Achieving deep carbon emission reductions in existing social housing: the case of Peabody

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Contents

Abstract

As part of the UK's effort to combat climate change, deep reductions in carbon emissions will be required from existing social housing. This thesis explores the viability of achieving such a goal through a case-study approach, focusing on Peabody, a large housing association operating in London.

A model was developed for Peabody's existing housing stock that quantifies the impacts of technical carbon reduction interventions on stock carbon emissions, Peabody's expenditure and residents' fuel bills for the period up to 2030. A participant observation study, conducted from 2006 to 2009, explored the impact of contextual factors influencing the viability of Peabody carrying out the considered technical interventions.

The model study found that the Greater London Authority's target of achieving 60% emission cuts by 2025 could be achieved, but only through extensive stock refurbishment, including a widespread use of solid wall insulation. An external context of substantial reductions in the carbon intensity of the national grid and constrained resident demand for energy is also required. Even where considerable financial support for refurbishment from Government was assumed, the model provided evidence of a funding gap of tens of millions of pounds which would need to be bridged if the required measures were to be carried out.

The participant observation study found that the prohibitive cost of carrying out carbon reduction measures is the key barrier currently holding back progress. Other significant issues are related to Government policy, including the inability to raise income from residents to offset refurbishment spending, and the lack of a long term framework to drive action to reduce emissions from existing UK housing.

By coupling an analysis of technical interventions with analysis of their financial and political viability, this thesis demonstrates that the achievement of deep emission cuts from Peabody's existing stock is certainly possible, but requires changes in Government policy and increased efforts from all stakeholders concerned if it is to come to pass.

Publications arising from this thesis

The following two documents based upon the work reported in the present thesis have been published prior to its submission:

Reeves, A. (2009). Towards a low-carbon Peabody. London, Peabody.

> *A research report detailing the findings from the model-based study in the present thesis (corresponding to chapters 5, 6 and 7, and parts of chapters 1, 2 and 9).*

Reeves, A., Taylor, S.C. and Fleming, P.D. (2009). Deep carbon emission reductions in existing UK social housing: are they achievable, and how can they be funded? ECEEE Summer Study: Act! Innovate! Deliver! Reducing energy demand sustainably, La Colle sur Loup, France, European Council for an Energy Efficient Economy.

> *A peer-reviewed conference paper detailing the findings from the model-based study that relate to the achievement of London's 2025 carbon emission reduction target.*

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Abbreviations and acronyms

ASHP:	Air Source Heat Pump
BBN:	Bayesian Belief Networks
BD:	Breaking Down scenario
BREDEM:	BRE Domestic Energy Model
CA:	Conservation Area
CASE:	Collaborative Awards in Science and Engineering
CDEM:	Community Domestic Energy Model
CHP:	Combined Heat and Power
CO_2:	Carbon dioxide
COM:	Communal refurbishment approach
COP:	Coefficient of performance
EEPfH:	Energy Efficiency Partnership for Homes
EPC:	Energy Performance Certificate
EPSRC:	Engineering and Physical Sciences Research Council
ESCo:	Energy Services Company
FAB:	Fabric refurbishment approach
FIT:	Feed-in Tariff
FP:	Fuel Poverty
G15:	Group of London social landlords
GLA:	Greater London Authority
GSHP:	Ground Source Heat Pump
GVA:	Gross Value Added
HCA:	Homes and Communities Agency
HESS:	Heat and Energy Saving Strategy
HHSRS:	Housing Health and Safety Rating System

INREB: Integrating New and Renewable Energy into Buildings

IPPR: Institute for Public Policy Research

KLO: Keeping the Lights On scenario

KPI: Key Performance Indicator

NPV: Net Present Value

PD: Power Down scenario

PEM: Peabody Energy Model

PV: Photovoltaics

REN: Renewables refurbishment approach

RHO: Renewable Heat Obligation

RO: Renewable Obligation

ROC: Renewable Obligation Certificate

RSL: Registered Social Landlord

SD: Sustainable Development scenario

SPC: Shadow Price of Carbon

SHIFT: Sustainable Homes Index For Tomorrow

TFA: Total Floor Area

TRV: Thermostatic Radiator Valve

TSA: Tenant Services Authority

UK: United Kingdom

UNFCCC: United Nations Framework Convention on Climate Change

Chapter 1: Introduction

In this chapter the research is introduced with reference to its principal aims and objectives (section 1.1). Climate change mitigation, and the resultant need for deep emission cuts from existing housing, is introduced as the main motivation for this research (1.2), followed by a short summary of existing research in this area and gaps in current knowledge (1.3). The social housing sector (1.4) and the case study housing association Peabody (1.5) are then described with reference to the issue of carbon emission reduction, followed by an introduction to the research on Peabody stock of which this thesis forms a part (1.6). The structure of the present thesis is given in 1.7.

1.1 Research aims and objectives

The broad aim of this research is to identify the viability of achieving deep carbon dioxide (CO_2) emission[1] cuts from the existing housing stock of Peabody, a social landlord operating in London. For the purpose of this research "deep" cuts can be understood as referring to reductions in carbon emissions of the order of 50% and beyond. This research aim is explored through a number of objectives which are based upon the aims of the wider research project (introduced in 1.6) of which this thesis forms a part. These objectives consider both technical interventions that can be applied to Peabody homes (such as solid wall insulation or micro-generation technologies) and contextual issues (such as planning constraints and resident energy demand) which affect the viability of carrying out refurbishment options and the emissions cuts that can be achieved. The objectives are:

> *Identifying the reductions in CO_2 emissions that can be achieved from existing Peabody homes in the period up to 2030, through the application of technical interventions*
>
> *Identifying the impact of contextual factors on the CO_2 emission cuts that can be achieved*
>
> *Identifying the financial implications of refurbishment approaches taken by Peabody — both for Peabody and its residents*

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[1] the terms "carbon emissions" and "CO_2 emissions" are used interchangeably throughout this thesis. Any references to quantities of emissions refer to carbon dioxide (CO_2), not carbon.

Through identifying the key issues affecting the achievement of deep carbon emission cuts for one social landlord, this thesis aims to make an original contribution to knowledge that will better inform actions taken towards meeting this goal by Peabody, Government, social landlords and other stakeholders in the social housing sector.

1.2 Motivation

The over-arching motivation for this research comes from the now widely-accepted need to greatly reduce the emissions of carbon dioxide and other greenhouse gases in order to mitigate anthropogenic climate change (IPCC 2007). This global imperative has been translated into challenging targets for carbon emission reduction in the UK (discussed in more detail in 2.1). The UK Government has recently committed to a minimum of 80% reductions in UK CO_2 emissions by 2050 relative to 1990 levels (DECC 2008). In London, the Greater London Authority (GLA) has set a target of a 60% reduction in carbon emissions by 2025 relative to 1990 levels in its Climate Change Action Plan (GLA 2007).

The need to reduce CO_2 emissions resulting from energy use in housing has been recognised as a key part of the UK's efforts to combat climate change (Boardman 2007; CLG Committee 2008; DECC 2009a). Energy use in housing contributes a significant proportion of end-use CO_2 emissions: 27% in the UK (excluding aviation and shipping) (Defra 2006a) and 44% in London (excluding aviation) (GLA 2006). Due to the likelihood that the majority of existing housing in the UK will still be in use by the middle of this century, consideration of climate change has led Government, researchers and stakeholders in the housing sector to call for a substantial programme of refurbishment of the UK's existing housing stock to achieve deep emission cuts (Boardman et al. 2005a; SDC 2006a; UKGBC 2008a; DECC 2009a).

Despite this identified need, progress to date with this ambitious carbon reduction agenda has been slow. Government policy and grant funding is still largely focussed on measures with relatively low upfront costs and short payback periods such as cavity wall insulation and loft insulation (WWF 2008). Installation rates for more costly and disruptive carbon reduction measures, such as solid-wall insulation and micro-generation technologies, are some way below those required for a pathway towards achieving 80% emission cuts by 2050 (ibid).

There is increasing consensus amongst researchers and Government that comprehensive whole-house refurbishments are likely to be required to achieve deep emission cuts in the housing sector (Boardman 2007; Killip 2008; DECC 2009a). However, as of 2008, only several dozen homes had been identified in the UK as being refurbished to such a standard (Killip 2008). A long-term strategy for existing housing refurbishment has not yet been decided upon by Government, contrasting sharply to the strategic steer given to energy use in new build housing (CLG Committee 2008). The UK Government's consultations on the Heat and Energy Saving Strategy (HESS) (DECC 2009a) and the Community Energy Saving Programme (CESP) (DECC 2009b) published in February 2009 have put forward some proposals for addressing this issue (discussed further in 2.6.3). Both documents stress the importance of refurbishing the UK's existing housing stock and the potential value of a whole-house and community-level refurbishment approach.

Alongside the issue of climate change, two central issues affecting domestic energy use are energy security and fuel poverty (Foresight 2008). The question of energy security is largely dependent on macro-level socio-economic issues and is therefore outside the scope of this research. Fuel poverty is a significant issue for social landlords, and is discussed further in 2.2.5 and addressed in this research by identifying the impacts of refurbishment approaches on resident fuel bills and fuel poverty levels.

1.3 Research need

Research on refurbishment of the existing UK housing stock has until recently focused on the challenge of achieving deep carbon emission cuts from the perspective of technical feasibility. Several studies have taken the approach of modelling energy use in UK housing stock, and each study has concluded that the targets considered for emission reductions by 2050 (either 60% or 80%) can be achieved (BRE 2005; Johnston et al. 2005; Boardman et al. 2005a; Boardman 2007; Energy Saving Trust 2008; WWF 2008).

Recommendations for policymakers to achieve these emission reductions have also been put forward, such as mandating improvements to existing dwellings, developing capacity in industry, and removing financial disincentives to refurbishment (Boardman 2007; Energy Saving Trust 2008; Killip 2008). A number of contextual factors that play an important role in achieving deep emission cuts have been identified, including decarbonisation of grid electricity and a rapid take-up of carbon reduction technologies (Boardman 2007; Energy Saving Trust 2008; UKERC 2009).

To date there has been little research addressing the viability of achieving deep cuts in carbon emissions from particular housing sectors (such as the social housing sector, or the private-rented sector). Existing research has to date done little to assess the financial viability of refurbishment approaches that achieve deep emission cuts, due in part to the many uncertainties involved in predicting costs over a very long timescale (Hinnells 2005).

This research addresses these gaps in the literature by considering the viability of achieving deep emission cuts within the social housing sector, and incorporating analysis of policy incentives, financial viability and other contextual factors. Analysis of costs is possible as this research covers the period up to 2030, rather than 2050, a timescale for which social landlords will typically plan for through their long term financial strategies. This shorter time horizon reduces uncertainties around costs, making it more appropriate to quantify the financial impacts of refurbishment.

1.4 Social housing

The UK social housing sector comprises 18% of UK homes (CLG 2008a) and exists to provide affordable housing. Provision is approximately equally split between local authorities and housing associations, such as Peabody, which are not-for-profit institutions that both manage and construct social housing.

Although the majority of homes managed in the social housing sector are “general needs” lettings, social landlords also offer sheltered housing, shared ownership homes, key worker homes and some open market lettings (typically used to cross-subsidise general needs lettings). In addition to tenants’ homes, social landlords are also responsible for the maintenance of the external fabric of homes occupied by leaseholders. The term “residents” is used in this research to describe all householders in homes managed by social landlords, as distinct from “tenants”, which is used for residents who rent their property.

Social landlords typically provide homes for more vulnerable members of society. They house a high proportion of elderly tenants, and tenant incomes are lower than the national average (with more than 50% of social tenants in the UK receiving housing benefit) (Housing Corporation 2006a). The social housing sector differs markedly from other housing sectors in that it is regulated and heavily influenced by Government policy. This is exemplified for the issue of carbon emissions by the current requirement for social housing dwellings to meet the Government’s Decent Homes standard (see 2.6.2) and the need for new social homes to meet higher environmental standards than other new developments if they are to receive Government funding (Housing Corporation 2006b). Government policies that go beyond the Decent Homes standard to mandate stronger action to reduce emissions in social housing, for example, by treating solid-walled homes or installing micro-generation, have not been forthcoming to date. The recent HESS consultation indicates that whilst new financial support will be available over coming years for more costly measures, through feed-in tariffs and CESP, mandatory action for social landlords prior to 2012 is not planned (DECC 2009a).

In this context, refurbishment to reduce carbon emissions has to date been largely restricted to relatively low-cost measures (loft insulation, draught-proofing, etc). The installation of more costly low-carbon or micro-generation technologies by social landlords is still rare and is typically reliant on grant funding support, with high costs being the main barrier identified to their take-up (Cooper and Jones 2008).

1.5 Peabody

Peabody (formerly "The Peabody Trust") was founded in 1862 and is one of London's largest housing associations, managing around 18,000 homes on nearly 200 estates. Its stock dates from the 19th century to the present day, with the majority being purpose-built blocks of flats (see Figure 1.1). Peabody is well known for its BedZED development, completed in 2002, which aimed to achieve net zero fossil energy use in its operations (Bioregional 2004).

Figure 1.1 A selection of Peabody estates

Peabody stock differs markedly in its makeup from other social housing stock and other housing in London (Table 1.1). It is older than typical housing association stock, much of which was built in the last 40 years, and older than other social housing in London. It does however have a broadly similar age profile to London's existing housing stock. Around 44% of homes on Peabody estates are in conservation areas and around 1% are listed (based on data from Peabody). This contrasts to an estimated 18% of housing in conservation areas in London (based upon Bottrill (2005) and CLG (2006)). Peabody therefore faces a particular challenge to achieve low emissions in its existing stock due to its greater than average proportion of older homes with solid walls, and the conflict with concerns for preserving architectural heritage.

	% homes built prior to 1945	% homes flats	Breakdown of non-flats	Source
Peabody	51%	82%	Remaining 18% mostly terraced or semi-detached	Peabody
All housing associations	19%	42%	48% terraced or semi-detached, 10% detached	CLG (2008)
London	58%	45%	33% terraced, 22% semis or detached	CLG (2008)
London social housing	31%	74%	20% terraced, 6% semis or detached	CLG (2008)

Table 1.1 Characteristics of Peabody stock relative to other housing

Peabody residents broadly match the general demographic profile reported previously for social housing, although they are more ethnically diverse, with the majority of recent lettings being to residents from black and minority ethnic backgrounds (CORE 2006). The vast majority of Peabody homes are general needs lettings, although there are some small estates or blocks that specialise in sheltered, supported or market rent housing. Due to the "right to buy" on estates transferred from local authorities and recent sales of homes on some other estates, many estates contain a wide variety of tenure types, including a significant proportion of leaseholders.

1.6 Research on Peabody stock

The work carried out for this thesis is part of a programme of research that has been carried out in cooperation with Peabody since 2002. This programme has aimed to identify stock improvement measures to be carried out over the coming 20–25 years in order to minimise resident fuel costs and CO_2 emissions, whilst ensuring that investments are financially viable.

From 2002 to 2003, research conducted on the energy performance of Peabody's existing stock identified actions needed to provide affordable warmth to residents over the short and long term. The consultancy Rickaby Thompson Associates (RTA) found that achieving an average SAP rating[1] of 70, taken as a proxy for achieving affordable warmth across the stock, would require investment of over £21m up to 2010 (RTA 2002). Due to financial constraints, these recommendations were not carried out, although many of the recommended measures are now being done through work to meet the Decent Homes standard.

A second report was undertaken looking at measures to be taken over a 25 year timescale with the goal of providing affordable energy to residents whilst reducing CO_2 emissions (RTA 2003). The report's principal recommendation was that Peabody should shift from the current practice of providing individual gas central heating to existing flats on dense, inner-city estates, and instead look to install communal heating, supplied by gas-fired combined heat and power (CHP). It was argued that this measure would reduce resident fuel costs, Peabody maintenance costs and stock carbon emissions. The research made the further points that Peabody should develop an Energy Services Company (ESCo) to manage energy provision, and install renewables such as solar thermal and solar photovoltaics (PV) where feasible. To date, aside from some grant-funded solar PV installations carried out prior to the study, none of these recommendations have been carried out and an ESCo has not been created, although the report's ideas have informed Peabody's strategic thinking on stock refurbishment.

As an outcome of the previous research, two PhD projects[2] were created to develop it further: the present research and a parallel PhD study conducted by Dwyer (forthcoming). Dwyer's research considers the issues raised by the two consultancy reports for one Peabody estate, Camberwell Green. This is a solid-walled estate consisting of several 6-storey blocks of flats, which was chosen as a representative example of Peabody stock. In Dwyer's study, the implications of different approaches to refurbishment for the estate are assessed under different fuel cost scenarios. Each approach is then assessed in terms of its impacts on carbon emission reductions, annual resident fuel costs and the financial case for refurbishment options. The work carried out for this thesis aims to extend the research performed to date by Rickaby Thompson Associates and to complement the PhD research by Dwyer.

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[1] Standard Assessment Procedure – a measure used by the UK Government to assess the energy efficiency of a dwelling
[2] both of which were INREB Faraday Partnership CASE studentships, funded by the Engineering and Physical Sciences Research Council (EPSRC)

1.7 Thesis Structure

This thesis has ten chapters, and the remaining chapters are summarised below.

Chapter 2: Literature review

Introducing the conceptual background for this research as established through a review of existing literature.

Chapter 3: Scoping interview study

Reporting the results of a scoping interview study of stakeholders in the social housing sector and introducing the research questions this thesis seeks to address.

Chapter 4: Methodology

Detailing the overall design for this research and outlining the chosen methodology: the development of the "Peabody Energy Model" to provide quantifiable results on the impacts of refurbishment, coupled with a participant observation study which investigated contextual factors affecting stock refurbishment for Peabody.

Chapter 5: The Peabody Energy Model

Describing the methods and assumptions used to develop the Peabody Energy Model, including the definition of scenarios and carbon reduction targets.

Chapter 6: Initial model results

Describing the initial results from the Peabody Energy Model, where four refurbishment strategies are assessed using four distinct future scenarios.

Chapter 7: Further analysis of model results

Providing further analysis of the model outputs. Includes assessment of the cost-effectiveness of interventions and the impacts of altering refurbishment approaches and contextual assumptions. Strategies for meeting carbon reduction targets are put forward.

Chapter 8: Participant observation study

Reporting the results of the participant observation study undertaken to identify the impact of contextual factors (both internal and external to Peabody) on the viability of carrying out carbon reduction interventions.

Chapter 9: Discussion

Summarising the key research findings with reference to the research objectives of this thesis, and contrasting with findings from prior research. Some key implications for Government policy are also put forward.

Chapter 10: Conclusion

A brief summary of the key findings and the original contribution to knowledge arising from this research, followed by discussion on future work arising from the present thesis.

Following the final chapter, there is a list of references used in this thesis, and a section of appendices containing relevant background information (such as survey forms and interview schedules).

Chapter 2: Literature review

This chapter details the relevant background issues for this research, established with reference to existing literature. It establishes the “conceptual framework” (Maxwell 2005) through which the issues addressed can be understood, and identifies current gaps in knowledge that this research seeks to fill. This role is also played by chapter 3, which reports the results of an initial scoping interview study with social housing professionals and states the research questions that this thesis seeks to answer.

Existing long-term goals for reducing carbon emissions are first discussed (2.1), with the targets that will be used in this research to assess progress on carbon emission reduction put forward. The factors affecting domestic energy use and carbon emissions are set out (2.2), with a simple framework put forward that describes the role of social landlords in influencing emissions from their stock. The carbon reduction interventions available to social landlords are then reviewed in 2.3. Research into the viability of achieving deep emission cuts from existing UK housing is reviewed in 2.4.

The determinants of action by social landlords to reduce stock emissions are then discussed, firstly by introducing some theoretical perspectives useful for conceptualising these issues (2.5), and then by exploring both external and internal contextual factors (2.6 and 2.7 respectively) that affect the viability of carrying out carbon reduction interventions. The main issues identified in the chapter are summarised in 2.8.

2.1 Long-term carbon emission reduction goals

This section explores the various long-term goals put forward for carbon emission reduction by policymakers and in existing literature, and the rationales behind these goals. This discussion is used to inform the stance taken on how to benchmark progress by Peabody on achieving emission reductions.

2.1.1 Carbon emission reduction targets

In the absence of an agreed long-term international framework for carbon emission reduction, the targets put forward by political institutions vary considerably. The UK Government has recently committed to a statutory target to reduce UK emissions by at least 80% relative to 1990 levels by 2050, an increase on a prior non-statutory target of a

60% reduction by that date (DECC 2008). The European Union (EU) has committed to 20% reductions of greenhouse gas emissions by 2020 relative to 1990 levels, increasing to 30% if other developed countries commit to a comparable level of cuts (European Commission 2009). Some local authorities in the UK have set out a more ambitious carbon reduction agenda than the UK Government, such as the Greater London Authority (GLA) which has set a target to achieve 60% reductions in London's carbon emissions relative to 1990 levels by 2025, as part of a process to achieve reductions beyond 80% over the long term (GLA 2007).

The UK Government's 80% target is backed by the UK's Conservative party, and many environmental campaign groups such as Friends of the Earth and WWF (WWF 2007). The Liberal Democrats in the UK have a more ambitious agenda, calling for a zero-carbon economy by 2050 (Liberal Democrats 2007). Reports by two independent environmental groups (the Centre for Alternative Technology and the Public Interest Research Centre) have called for total decarbonisation of the UK economy within the next few decades (CAT 2007; PIRC 2008).

The great range of approaches illustrated above shows that the setting of carbon reduction targets, although informed by the scientific research on climate change, is undoubtedly also a political process. Given the divergence between targets put forward by different bodies and changes in their levels over time, a decision on which target it would be appropriate to test emission reductions at Peabody against requires some further exploration of the rationales behind existing aspirations.

2.1.2 Rationales for carbon reduction targets

If concerns for the political acceptability of carbon emission reduction targets are put aside, their rationale can be usefully understood using a framework that takes into account three principal issues: consequences (the impacts of climate change that action to reduce emissions seeks to avoid); science (the science that underlies assessments of the connection between emissions and climate change); approach to risk (given the uncertainties inherent in climate science, the likelihood of undesired consequences of climate change taking place that is judged to be acceptable).

This distinction is intended to underline that while climate targets are often put forward by both politicians and campaigners as being a result of scientific judgement, they also rely on two normative elements, a judgement of the consequences which interventions seek to avoid, and a judgement on an acceptable level of risk of those consequences being avoided (Schneider and Lane 2006).

2.1.2.1 Consequences

Discussion of the consequences that climate change mitigation seeks to avoid has been heavily influenced by the United Nations framework convention on climate change (UNFCCC), which called for “stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (United Nations 1992). The meaning of “dangerous” was not defined at the time (Schneider and Lane 2006), but since that time the goal of avoiding “dangerous climate change” has been a commonly stated goal of policy, including in the UK (Defra 2006a). In 1996, the European Union equated dangerous climate change with a 2°C rise in average global temperatures above pre-industrial levels (WWF 2007), an approach that has persisted to the present day (European Parliament 2009). This position has been adopted by many other state and non-state actors including the UK Government, and has become the most commonly used interpretation of the concept of dangerous climate change.

The 2°C target has become increasingly contested in recent years, based upon a context of undesirable climate change impacts such as rapid losses of arctic sea ice already becoming apparent (PIRC 2008). The latter issue has led several reports to argue that climate change is already “dangerous” in the sense intended by the UNFCCC (Spratt and Sutton 2007; PIRC 2008), despite an increase in average temperatures of only 0.8°C to date. Such concerns have led to lower temperature thresholds being put forward, including a suggested limit on increases in global temperature of 1.7°C (Hansen 2007) and a redefined threshold for “dangerous” climate change of 0.5°C (Spratt and Sutton 2007). The argument for a lower threshold temperature is supported by research which suggests that the irreversible decline of the Greenland ice sheet, which would eventually bring about global sea level rises of up to 7 metres, would be triggered by an average global temperature increase in the range 1–2°C (Lenton et al. 2008).

2.1.2.2 Climate science

Given a particular level of warming that mitigation of climate change seeks to avert, climate science can then be used to provide evidence on the action needed to avoid this outcome, typically through the outputs of long-term climate system models (Monastersky 2009). These outputs are commonly reported in terms of the atmospheric CO_2 concentrations that are compatible with meeting a given target, and given the uncertainty involved in climate modelling, an associated probability that a particular stabilisation goal will lead to a target being met (IPPR 2006; PIRC 2008).

Government policy in the UK has shifted during the last decade from being based upon a 550 ppm CO_2 stabilisation goal, through to a range of 450 to 550 ppm CO_2 equivalent[1] advocated in the Stern review (Stern 2006), to a goal of 450ppm CO_2e that underlies the new 80% carbon reduction target (and the GLA target for 2025). Research relating to a 450ppm CO_2e target indicates that it would give approximately a 50% chance of preventing the 2°C threshold from being crossed, although there is significant uncertainty around this figure (Meinshausen 2005).

More recent research has indicated that this probability of success may in fact be lower. Hansen et al. (2007) put forward evidence that the Earth's long-term sensitivity to greenhouse gas emissions could be up to twice the level assumed previously, which would imply that significantly more warming would be associated with given atmospheric CO_2 concentrations than assumed in previous research, although there is not consensus amongst climate scientists that this is the case (Monastersky 2009). Anderson and Bows (2008) showed that modelling used to inform research on 450ppm CO_2e stabilisation (including the assessment by the UK's Committee on Climate Change that led to the 80% reduction target for 2050 being adopted (CCC 2008)) relies upon estimates of emissions since 2000 that are lower than those that occurred in reality. The implication is that greater emission reductions than previously thought would be required to meet a particular target, such as keeping warming below the 2°C threshold.

2.1.2.3 Approach to risk

As the discussion above illustrates, the carbon reduction targets adopted by the UK Government and the GLA are based upon an assumption that a probability of success of around 50% is the minimum acceptable. This is a normative question, and approaches differ in literature that addresses it, with some authors agreeing with a 50% likelihood of success being an appropriate minimum value (WWF 2007), and others explicitly calling for a greater degree of confidence that climate policies will be successful (IPPR 2006; Public Interest Research Centre 2008; Stockholm Network 2008). Researchers taking the latter

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[1] or "CO_2e", referring to the net impact of all gases that impact on global temperatures

approach have demand a level of confidence of at least 90% (Stockholm Network 2008) or 80% (IPPR 2006) that 2°C warming is not exceeded.

A concern to increase the likelihood of avoiding unwanted impacts of climate change leads to significantly greater emission reductions being required. This has led to calls in some studies by advocates for action on climate change to rapidly phase out the use of fossil fuels for energy, and to potentially consider actively drawing down carbon from the atmosphere (CAT 2007; Spratt and Sutton 2007; Public Interest Research Centre 2008).

2.1.2.4 Summary

The current political consensus on climate change mitigation in the UK can be understood as an aim for 450ppm CO_2e stabilisation by 2050 with a target of achieving 80% emission reductions by that date. In terms of the consequences it seeks to avoid, the science underlying it and the approach to risk it embodies, this target appears to be best described as a minimum level of action to mitigate climate change, due to the many issues identified pointing to a case for greater emission cuts. A number of studies that have taken these issues into account have argued for a much more radical agenda, which can be thought of as representing an upper limit in the range of possible action, of achieving an entirely zero-carbon UK economy within just a few decades.

2.1.3 Implications for this research

The discussion in this section has illustrated that targets set by Government and local authorities exist that can be used to assess progress in carbon emission reduction at Peabody over the period to 2030, with the 2025 target set for London being the principal candidate. However, recent history has shown that targets set by governments have tended to become more stringent over time, and the many issues discussed above indicate a number of possible motives for adopting a more stringent target.

This thesis therefore takes the approach of using two distinct targets for assessing the impacts of emission reduction interventions for Peabody. The GLA target for 2025 is used, as this represents the key political target that applies to a London social landlord such as Peabody, and fits within the time horizon considered in this research. In addition, the viability of achieving the upper limit aspiration discussed above, of achieving zero net carbon emissions on Peabody estates by 2030 is also assessed. Alongside these assessments, the extent of emission reductions that can be achieved in Peabody stock between these two extremes through the various intervention approaches considered is also reported.

2.2 Context of domestic energy use and carbon emissions

In this section, key issues relating to domestic energy use are introduced, including carbon emissions, fuel costs and fuel poverty. A simple framework for conceptualising domestic energy use that highlights the role of social landlords in addressing carbon emissions is put forward.

2.2.1 Definitions, statistics and recent trends

For the purposes of this thesis, domestic energy use is defined as energy used directly within households. It therefore includes energy used for space heating, hot water, cooking and electricity, and excludes issues such as transport, waste and purchases of consumer goods. Domestic carbon emissions are the emissions that result from the use of fossil fuels to provide this energy either directly (such as gas for central heating) or indirectly (such as coal used in power stations to generate electricity). The majority of energy in UK homes is used for space heating (58% on average), followed by hot water (25%), lights and appliances (14%) and cooking (3%) (EST 2008a).

Over recent decades, total domestic energy demand has remained broadly stable with the impacts of increased efficiency of building fabric and appliances being offset by increases in household numbers and increased demand for energy services (BRE 2008a). In contrast, domestic carbon emissions have fallen slightly over this period, largely due to decarbonisation of grid electricity, although this trend has halted in recent years due to an increased use of coal-fired power stations (ibid). Trends in energy demand by end use are discussed in 5.5.

2.2.2 Understanding domestic energy use

The determinants of domestic energy use are highly complex and include meeting the basic needs of householders and interrelationships between technologies, social values, social norms and behavioural preferences (Jackson 2004; Keirstead 2006a; Faiers et al. 2007; Shove 2009). These issues can be usefully thought of as related to both macro-level factors, such as technological change, economic conditions and cultural trends, and micro-level factors such as the motivations, attitudes and opportunities for behaviour change of householders (Abrahamse 2005).

A conception of domestic energy demand that takes socio-cultural issues into account has not always been employed or explicitly acknowledged in research on energy use in housing (ECI 2007). Studies that evaluate carbon reduction interventions in terms of "technical potential" without considering a broader concept of what is socially acceptable run the risk of advocating measures that may not be feasible, and perhaps not desirable, when non-technical considerations are taken into account (Shove 1998). Examples of this include giving insufficient weight to the comfort of building-users when planning fabric improvements (Bahaj 2006), or under-estimating the detrimental impact on existing communities when considering demolition and rebuilding as a carbon reduction strategy (Power 2008).

Based upon this understanding of domestic energy use, this research considers the impacts of technical interventions alongside evidence on their viability and acceptability from the perspective of Peabody and its residents, to provide a more detailed analysis of the emission cuts that can be achieved.

2.2.3 The social landlord's role in influencing stock carbon emissions

The role of social landlords in influencing emission levels in their stock largely relates to their responsibilities to carry out maintenance and improvements to homes so that the homes continue to meet the needs of tenants. The cyclical maintenance programmes and estate-wide improvements employed by social landlords can be usefully understood as interventions carried out to prevent the homes they manage from becoming obsolete (Jones 2002). Obsolescence relates to a building no longer meeting its requirements, which could occur for a number of reasons including physical deterioration, installed technologies becoming obsolete, or societal changes leading to changed requirements for use of the building (Flanagan and Jewell 2005). A particularly important measure of obsolescence for social landlords is the lettability of a dwelling. For example, a dwelling could become obsolete if it became prohibitively expensive to heat, deterring residents from taking up tenancies. For the purposes of this study, homes could also be understood to be obsolete if they can not respond to the new requirement considered of delivering low carbon emissions from their use.

Taking the issues discussed above into account, the role of social landlords in influencing domestic energy use and carbon emissions can be conceptualised (Figure 2.1). The diagram illustrates that domestic energy use is due to the inter-relationship between resident behaviour and the physical energy systems in a resident's home (building fabric and energy using devices). Carbon emissions are the result of energy use coupled with the carbon intensity of fuels used. Fuel bills for residents are a result of energy use coupled with fuel costs. There is a potentially significant feedback in the system, whereby fuel bill levels could influence energy use behaviour, for example by reducing demand if fuel bills were perceived to be high.

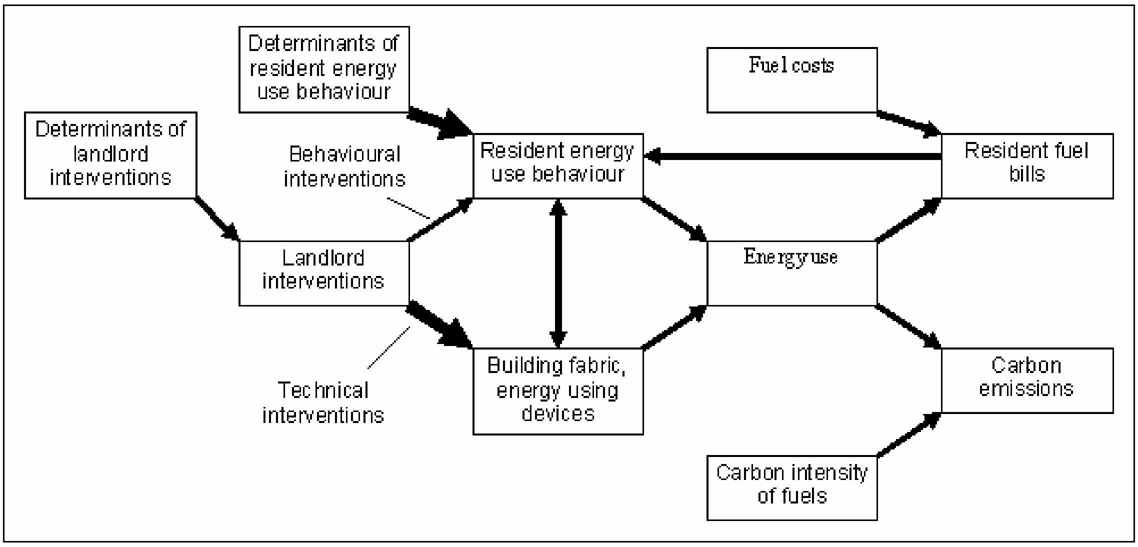

Figure 2.1 The social landlord's role in domestic energy use

The principal role of landlords in influencing domestic energy use comes through technical interventions that alter the physical properties of residents' homes and the installed energy using devices. Landlords can also make behavioural interventions to affect resident energy use behaviour, such as offering guidance on the efficient use of heating systems. Given the wide-ranging social determinants of this behaviour outlined in 2.2.2 and the strong role of other actors (such as national and local government, utility companies and agencies working on household energy issues) in intervening to affect behaviour, the impact of such interventions from social landlords is likely to be relatively limited (indicated by a smaller arrow). The determinants of action by landlords are discussed in sections 2.5 to 2.7.

It is recognised that the framework put forward in Figure 2.1 is a relative simplification, and a number of other relevant issues are not illustrated. For example, residents also play a role in selecting the energy using devices used in their homes, and social landlords are able to intervene to an extent on this issue, for example by using bulk discounts to make energy efficient appliances more affordable for residents. Landlords can also influence the Government policies that drive action on their part through lobbying, and can determine resident fuel costs if they are directly providing energy.

This research is primarily concerned with technical interventions that can be made by social landlords (discussed in 2.3) and the determinants of action to carry them out. This focus is due to these interventions being more within the remit of social landlords than behavioural interventions, and due to evidence (discussed in 2.4) that technical measures are likely to be necessary to achieve deep emission cuts.

2.2.4 Determinants of domestic energy use and carbon emissions

Given the complex factors that determine levels of domestic energy use discussed above, researchers have found it challenging to account for and predict. A number of identifiable factors have however been shown to be related to energy use levels, and are set out in this section, alongside some implications for energy use in the social housing sector.

Demographic factors and dwelling size are the key issues that have been shown to affect energy use. Research based upon monitored energy use has shown that use of energy for space heating increases with dwelling size, income, age of occupants and number of householders (Brandon and Lewis 1999; Hong et al. 2006; Baker 2007). Demand for hot water appears to increase linearly with the number of householders (DTI 2005a). With regard to electricity use, in one of the most comprehensive studies available in the literature which uses data from 50,000 households in Denmark, Gram-Hanssen and Peterson (2004) found that the number of residents is the strongest determining factor, followed by income and dwelling area. Mansouri et al. found that factors such as the number of residents, dwelling size and income accounted for 61% of the variation in electricity use, with the remainder due to behavioural issues (Mansouri et al. 1996).

The correlation between both smaller dwellings and lower income levels with reduced energy use implies that energy use is likely to be lower in the social housing sector relative to other tenures. This result was found in a number of studies addressing both heating and electricity (Walker and Oseland 1997; Brandon and Lewis 1999; BRE 2003; Firth et al. 2008). In terms of social and behavioural factors, an attitude of “energy saving” has been shown to be connected to lower electricity use (Gram-Hanssen and Peterson 2004). Research by Walker and Oseland (1997) found that the closely related attitude of “frugality” was common amongst social housing tenants. Research that used Peabody residents as a case study has indicated that carbon emission reduction appears to be far less likely to motivate social housing tenants to reduce energy use than an interest in saving money (Islington Council 2003).

The key determinants of energy use noted above are therefore related to demographic characteristics and dwelling size, and not to the issues of built fabric or energy supply systems that landlords are best-placed to influence. Nevertheless, despite the complex factors that establish each individual household's level of energy use, there is extensive evidence that technical and behavioural interventions can reduce energy use, and as a result, carbon emissions (Bell and Lowe 2000; BRE 2003; Darby 2006).

Given the social and behavioural determinants of energy use, future trends in energy demand are likely to be largely dependent on broad social changes. A number of key issues that could affect this are the potential impacts of climate change on demand for space heating and cooling (ARUP 2008), future fuel price levels, and future demographic changes (Boardman et al. 2005a). These issues are explored in more detail in chapter 5.

2.2.5 Domestic energy costs and fuel poverty

Over recent decades domestic energy prices have declined in real terms, although this trend has reversed in the last few years, with both gas and electricity prices increasing sharply (BERR 2008b). These fuel price increases have greatly increased the political profile of the issue of fuel poverty.

A household is defined by the UK government as being in fuel poverty if it needs to spend more than 10% of its total income on fuel to provide an adequate level of energy service (Defra 2004a). A statutory target exists to eliminate fuel poverty in English social housing by 2010, and in all housing by 2016, though current trends point towards both targets being missed (NEA and Energy Action Scotland 2008). Groups such as the fuel poverty charity National Energy Action (NEA) advocate an alternative definition where disposable income (total income excluding housing costs) is considered instead of total income, with the same 10% fuel poverty threshold being used (NEA 2008). To simplify analysis, this thesis has used only the Government definition to analyse fuel poverty, although the effects of using the NEA definition were explored in Reeves (2009).

Due to their relatively low incomes, social housing residents are at particular risk of being brought into fuel poverty if fuel prices go up, and this appears to have taken place due to price increases in recent years (EEPfH 2007). The future prospects for eliminating fuel poverty appear challenging, due to the potential for fuel prices to increase in real terms in coming decades. A likely trigger for this would be an increase in crude oil prices, as fuel price levels have been historically correlated with the price of oil, a trend which is likely to continue for the foreseeable future (Powry Energy 2007). Oil prices appear likely to increase in real terms over coming decades, due to a context of supply struggling to match demand (IEA 2008; Tsoskounoglou et al. 2008).

Fuel poverty can be reduced by reducing fuel prices, reducing the need to spend money on energy, or increasing incomes (EEPfH 2007). Social landlords can act on all three of these issues by respectively: supplying energy to residents at a reduced price (for example, by installing communal heating and fixing the sale price of heat below rates charged by utility companies); improving energy efficiency of dwellings or installing micro-generation; supporting residents to maximise their income. The former two approaches are of interest for this research, so the impacts of possible technical interventions on fuel poverty levels amongst Peabody residents are assessed in chapters 6 and 7.

2.2.6 Summary

This section has established the context of domestic energy use and factors affecting carbon emissions relevant for this research. It has been argued that social landlords can carry out technical and behavioural interventions to attempt to reduce carbon emissions and fuel poverty levels in their stock. A focus in this research on analysing the emission reductions that can be achieved through technical interventions coupled with analysis of financially viability and social acceptability has been put forward.

2.3 Carbon reduction interventions

This section summarises the principal interventions available for a social landlord such as Peabody to reduce carbon emissions from its existing stock. Two broad categories of intervention are considered, following the terminology introduced in 2.2: technical interventions (2.3.1), defined as interventions that alter the built form or energy using systems of dwellings, and behavioural interventions (2.3.2), that seek to change the energy use behaviour of residents. It is recognised that despite this split being made to facilitate discussion, there is significant overlap between these categories, with the success of technical measures often being reliant on successful householder engagement (Sustainable Homes 2004), and some behavioural measures involving the installation of physical equipment (such as smart meters or feedback monitors).

The interventions reviewed are based upon the measures considered by Dwyer (forthcoming), and literature discussing possible technical measures (EST 2004a; Defra 2006b; Hinnells 2008) and behavioural measures (Abrahamse et al. 2005; BRE 2006a; Darby 2006). For each measure considered, some key issues affecting its take-up by social landlords are highlighted, alongside whether or not its use has been considered for Peabody stock in this research.

Other actions by social landlords that do not aim to achieve carbon emission reductions (such as installing digital television infrastructure) may also lead to changes in emission levels, so in order to consider “landlord interventions” (as per Figure 2.1) in its totality, the impacts of other interventions are also discussed in 2.3.3.

2.3.1 Technical interventions

The technical measures available to social landlords can be grouped in terms of the low to medium cost measures (such as draught proofing or cavity wall insulation) that are currently being carried out in social housing through Decent Homes programmes (2.3.1.1), and more disruptive and high cost measures (such as solid wall insulation or micro-generation) that have lower levels of take-up (2.3.1.2 to 2.3.1.5) (Housing Forum 2009). The role of emerging technologies is also discussed (2.3.1.6), followed by the potential use of “demolition-and-rebuild” as an alternative strategy to refurbishment (2.3.1.7) and discussion on the use of off-site renewables (2.3.1.8).

2.3.1.1 “Decent Homes” measures

This category includes measures such as loft insulation, cavity wall insulation, boiler replacement with efficient gas boilers, improved heating controls, draught proofing and installing energy efficient lighting, which are currently seen as cost-effective (Defra 2007a; Housing Forum 2009). Progress in installing these measures has been more rapid in the social housing sector than for other tenure types in recent years due to the requirement to meet the Decent Homes standard by 2010 (ODPM 2004). Their impact is taken into account in this research by calculating the emission reductions achieved by 2010 in Peabody stock through work to meet the Decent Homes standard. The main focus of this research is however on the impacts of more costly and disruptive interventions which could be carried out from 2011 onwards (discussed in chapter 5).

2.3.1.2 Other fabric measures and ventilation

This category is largely concerned with more costly and potentially disruptive measures to reduce the rate of heat loss from dwellings, such as solid wall insulation, floor insulation and double (or secondary) glazing. These measures are associated with greater upfront installation costs, of the order of thousands of pounds per dwelling (Housing Forum 2009).

Although the resultant fuel bill savings can make these measures potentially pay back within their lifetimes, especially if refurbishment is taking place already so that only marginal costs need to be considered, the high upfront costs and relatively long payback periods have led to slow progress in the UK in their installation (Defra 2007a; Adams 2008).

Fabric improvements will often bring with them a requirement for other interventions (Purple Market Research 2009). Double glazing would be a likely requirement alongside solid wall insulation to prevent condensation (EST 2004a). Improved airtightness in dwellings would also be likely to create the need for improved controlled ventilation. This could take the form of simple extractor fans in “wet rooms” or, especially in more air-tight dwellings, whole-house mechanical ventilation with heat recovery (MVHR) or heat recovery fans (EST 2004a). Practitioners recommend that fabric improvements are carried out as a package of measures to provide an overall improvement in dwelling performance (Purple Market Research 2009). As a result, fabric improvements are considered in this way in this research, with double glazing and extractor fans being installed (where required) alongside solid wall insulation. Secondary glazing is not considered, due to maintenance problems experienced by Peabody in the past, and a consequent preference for double glazing.

Going beyond the measures described above is “Passivhaus refurbishment”, which seeks to substantially increase insulation levels and airtightness in pursuit of achieving the Passivhaus standard in refurbished dwellings (Energie Institut 2007). This approach, which is currently being trialled in some UK social housing (Trecodome 2009), offers the potential benefits of achieving substantial reductions in space heating requirements for homes, at the cost of a more complex and costly refurbishment process. To simplify the analysis of fabric improvements, it has not been considered in this thesis, although its possible impacts were explored in Reeves (2009) and are briefly reported in 7.1.2.

2.3.1.3 Individual heat technologies

Biomass is a potential low-carbon fuel for individual households, with the two main options being wood-burning stoves for individual rooms or wood boilers to provide central heating to whole houses. Their use however poses concerns related to particulate pollution which may prevent a widespread application in urban areas (BERR 2008a). Their use in social housing is potentially limited, as social landlords may be reluctant to place an increased responsibility on their tenants, who are often elderly or vulnerable, to maintain and manage a heating system that requires the use of bulky fuel.[1] Their application for Peabody stock is therefore not considered in this research.

2.3.1.4 Communal heat technologies

In densely populated urban areas such as central London where Peabody operate, district heating networks have been advocated by both national and regional Government as an efficient and potentially low-carbon method of providing heat to buildings (GLA 2007; Greenpeace 2006; DECC 2009a). These networks can be fuelled initially by gas-fired combined heat and power, providing an increase in the overall efficiency of gas and electricity production, and have potential over a longer term to be fuelled by renewable biofuels. In London, the GLA has set the target of 25% of the city's energy being supplied by decentralised energy systems by 2025, and the majority by 2050, involving a significant use of district heating networks (GLA 2007).

Social landlords also have the option of developing communal heating on their own estates. Gas-fired combined heat and power engines or biomass boilers can be installed to make this a low-carbon option. A number of regulatory, financial and commercial barriers make communal heating installations problematic at present, including high costs of installing pipework, the financial risks involved for investors (due to uncertainty in costs and income levels over the investment period), and a resultant lack of a financial case for investment in many cases (DECC 2009a). Communal biomass boilers face the same potential barrier relating to concerns about particulate pollution as individual biomass systems (BERR 2008a).

Although communal heating is being increasingly installed for new developments, such as Peabody's BedZED and Coopers Road estates, very few examples exist to date of communal heating displacing existing individual heating systems. Nevertheless, in the light of the strong support being given to district heating in London by the GLA, prior research recommendations to Peabody to consider communal heating (RTA 2003) and positive experiences with district heating in other countries (Vital Energi 2005), the potential application of district heating or communal heating for individual estates (supplied by either CHP or biomass boilers) is considered in this research.

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[1] This viewpoint was identified through interviews with social landlord staff for the scoping interview study carried out for this thesis.

2.3.1.5 Micro-generation technologies

The micro-generation technologies explored in this research are solar photovoltaics (PV), solar thermal and heat pumps. Solar PV can be installed to provide renewable electricity on social housing estates. Only a small number of case study installations of this measure exist in UK social housing, all carried out with grant funding support, including projects on two Peabody estates (EESD 2002; Generating Solar Homes 2006). A payback period that exceeds the expected lifespan of the technology (Croxford and Scott 2006) and the resultant lack of a financial case for PV has been a key barrier preventing a more widespread use of the technology amongst social landlords (Generating Solar Homes 2006). Current Government plans to bring in feed-in tariffs to support micro-generation may change this situation in future years (BERR 2008a; REA 2009).

Solar thermal is a technology that can be used to provide hot water for households, using either flat plate or evacuated tube collectors. As with solar PV, solar thermal has been rarely installed by social landlords due to financial considerations, as it also currently has a payback period that exceeds its expected lifespan (Croxford and Scott 2006).

Heat pumps are typically classified as a micro-generation technology (e.g. EST 2007b; Element Energy 2008), as they capture renewable heat from their local environment, although they can also be thought of as a highly efficient way of using electricity to provide heat. Ground source heat pumps (GSHPs) or air source heat pumps (ASHPs) would be the most viable heat pump options available to social landlords operating in London. Their take-up so far in social housing has been limited to a small number of housing associations (Generation Homes 2007; Ryedale Energy Conservation Group 2007), typically in rural areas where gas central heating is not an option. Their take-up in urban areas could be limited both by the potential for fuel bills to increase if they replace gas central heating and in the case of ground source heat pumps, by the availability of suitable land around dwellings for burying pipework (Housing Corporation 2008a).

2.3.1.6 Emerging technologies

The potential for new technologies to come to market or become fully mature is significant where refurbishment is considered over a relatively long timescale, as is the case in this research. In terms of quantitatively assessing refurbishment options, a conservative approach of considering only fully mature technologies has been employed. The motives for not considering a number of technologies that were close to being included in this study are set out below.

Biomass CHP could play an important role in supplying heat to social housing estates, but is not yet considered to be mature for the medium-scale applications that would be relevant for this research (RAB 2007). Its application is therefore not considered as part of any refurbishment approaches, although its theoretical impact on emission levels is considered where the prospects for making Peabody estates zero-carbon are assessed (7.4).

Despite their widespread availability, building-integrated micro-wind turbines were not considered as they appear unlikely to offer significant opportunities to reduce emissions on the majority of urban dwellings (Booth 2007; Encraft 2008), and all Peabody homes are in an urban area (London).

Trials of microCHP have found that it is likely to be most effective at reducing carbon emissions in large dwellings with a consistent high heat demand (Carbon Trust 2007). For social landlords such as Peabody which have smaller than average homes, this technology is unlikely to be well-suited to the majority of their stock, so it was not considered. MiniCHP is an emerging technology that can provide heating to small clusters of dwellings. It may have potential to be applied on particular estates or parts of estates in Peabody's portfolio (RTA 2003), but identifying such sites was beyond the scope of this research.

A number of other technologies such as phase change materials or fuel cell CHP for individual dwellings could each play a role in reducing emissions in housing over future decades, but were not considered as they are not yet commercially available.

2.3.1.7 Demolition and rebuild

There has been considerable debate in recent years on the virtues of achieving emission reductions by demolishing inefficient housing and replacing it with new highly-efficient homes. The 40% house report (Boardman et al. 2005a) strongly made the case in favour of a greatly increased use of this approach. A number of studies have responded to this perspective by arguing that considerable emission reductions can be achieved by improving existing housing (BRE 2006b; Changeworks 2008), and that where embodied energy is considered, a life-cycle analysis of carbon emissions favours refurbishment over demolition (EHA 2008; Power 2008). Alongside these energy considerations, the social impacts of demolition can be a strong motivation to avoid this approach, which can be deeply unpopular with the communities affected (Joseph Rowntree Foundation 2006; Power 2008).

Even where demolition has been advocated by researchers, heritage dwellings have been described as “sacrosanct” (Boardman et al. 2005a). As a result, in Peabody’s case, where the majority of its solid-walled stock is in conservation areas, demolition is unlikely to be a viable carbon emission reduction approach for most estates. Due to these considerations, and a research goal of identifying the emission reductions that can be achieved through improvements to Peabody’s existing stock, the impacts of demolition and rebuild are not explored in this research.

2.3.1.8 Off-site renewables

The intervention of funding off-site renewables, such as wind turbines, was recommended to Peabody as a carbon reduction measure in previous research (RTA 2003). This intervention is not modelled in this thesis, due to the focus on what can be achieved through improvements to the Peabody stock itself. Evidence on its acceptability to Peabody staff is reported in chapter 8.

2.3.2 Behavioural interventions

In this section the background to behaviour change measures is introduced, followed by a discussion of possible measures available to social landlords, and the approach taken to their consideration in this research.

2.3.2.1 Background

Interventions to change energy use behaviour can be categorised as either related to changing habits of energy use or changing purchases (Barr et al. 2005). Existing literature on energy efficiency in social housing has focussed largely on interventions to change habits (BRE 2006a; Housing Corporation 2008a). The provision of information is the main recommended action, such as by creating “energy champions” on estates or organising awareness raising events (Housing Corporation 2008a). More radical approaches have also been put forward, such as linking rents with energy use, setting targets for energy use and reporting on energy issues at residents’ meetings (EST 2004b), but no examples of their use are known to the author.

A key issue identified in literature is that information and awareness raising strategies are most effective when coupled with motivation on the part of householders to reduce energy use (AGO 2002; The Prospectory 2008). As discussed in 2.2.4, social housing tenants are likely to be more responsive to interventions framed in terms of money savings, but there may be little potential to achieve further savings as they are likely to already be relatively frugal. The low priority attached to reducing carbon emissions may result in awareness-raising focussed on this issue having a low impact.

2.3.2.2 Advice and support

Energy efficiency advice can take many forms, such as leaflets distributed to tenants, a dedicated hotline, or face-to-face visits offering tailored advice. Research on the effectiveness of advice in social housing has revealed a relatively poor impact (Walker and Oseland 1997; Bahaj and James 2007). Unsolicited face-to-face advice was shown to have no discernible impact in Walker and Oseland's study, due to the tenants concerned already being relatively frugal. The study by Bahaj and James showed a drop in energy consumption immediately following advice, which was not sustained over the long term.

A related issue is the provision of guidance on the efficient use of installed energy supply systems. This is a significant issue, both in terms of the efficient use of controls for gas central heating (ACE 2005a) and the extent to which householder behaviour can significantly affect the efficiency of low-carbon technologies (Sustainable Homes 2004; BRE 2008b). Projects offering extensive tailored face-to-face advice on domestic energy efficiency to low-income householders such as the Green Doctor project have successfully addressed these issues (Devine-Wright and Devine-Wright 2006).

2.3.2.3 Feedback

Feedback on energy consumption can be provided to householders in a variety of ways, such as through bills, the internet, or dedicated monitors, and can focus on either energy consumption itself, expenditure or carbon emissions (Darby 2006). Research on the impacts of feedback has indicated that it is both a valuable complement to other energy saving interventions, and can lead to energy savings in itself of the order of 15% (ibid). The provision of feedback to UK householders is likely to increase significantly over the next decade due to the Government commitment to roll-out smart metering technology by 2020, which will enable utility companies to provide more accurate bills and energy use data to householders (DECC 2009c).

Social landlords can currently enable residents to receive direct and historic feedback on electricity consumption through the provision of feedback monitors. Trials of these monitors in social housing have indicated potential for reductions in electricity use of beyond 10% to be achieved (Places for People 2007). Current Government plans are for these monitors to be installed alongside smart meters by 2020 (DECC 2009c).

It has been suggested that the installation of micro-generation technologies such as solar PV or ground source heat pumps could also act as an effective form of feedback by giving householders a greater awareness of the energy system supplying their home (Keirstead 2006b; Bergman 2009). The evidence to date on whether this positive impact is realised is however ambiguous (ibid). Studies focussed on the impacts of PV in social housing have not identified any reductions in electricity demand (Bahaj and James 2007; Kirwan 2008).

2.3.2.4 Purchase-related behaviours

In the case of social housing, purchase decisions on the most significant products that affect energy use (boilers, building fabric, etc) are the responsibility of landlords. However, there is some scope for social landlords to influence purchase-related behaviours relating to appliances, through using bulk-buying or the negotiation of bulk-discounts to increase the affordability of more efficient appliances for residents. Case studies where this has been carried out are unknown to the author.

2.3.2.5 Approach to behavioural interventions in this research

The discussion above indicates that a number of behavioural interventions are available to social landlords such as Peabody (e.g. providing feedback monitors, energy efficiency advice, subsidised low-energy appliances and tailored guidance on use of appliances). Beyond the provision of basic energy efficiency advice, few of these interventions are widespread at present. Due to the great difficulty of quantifying the impacts of behavioural interventions (Devine-Wright and Devine-Wright 2006), the application of particular behavioural interventions has not been considered in the model-based study undertaken in this research. Their potential impacts were instead taken into account through assuming changes in levels of energy demand for each scenario under which model outputs were assessed (described in chapter 5). The viability of carrying out behavioural interventions was also explored through the participant observation study reported in chapter 8.

2.3.3 Other interventions impacting on emissions

By the framework for analysing energy use in social housing put forward in section 2.1.3, energy use can be understood as being affected by a wide range of landlord interventions. This chapter has so far considered carbon reduction interventions alone, so for completeness, other interventions that may also influence carbon emissions should be discussed.

An example of such an intervention is the provision of digital television infrastructure to social homes, which may have the impact of increasing electricity use through an increase in standby loads. Another example is landlord policies that affect the number of people living in their stock, such as allocation procedures and interventions to prevent sub-letting. The impact of household size is complex, as larger households typically have both greater levels of energy use but lower energy use per person. Increased household sizes therefore increase emissions for that particular landlord, but are beneficial in emissions terms from a societal perspective, as per capita emissions are reduced.

In this research the impacts of specific landlord interventions that may impact on emissions are not assessed. Their impacts can therefore be thought of as being taken into account through the assumptions affecting energy demand levels in each scenario considered.

2.3.4 Summary

The discussion above has highlighted the availability of both technical and behavioural interventions available to social landlords to reduce emissions. For this research, only mature technologies that are likely to be applicable for a significant proportion of Peabody stock are to be investigated. This comprises low-cost energy efficiency measures, packages of fabric improvements, communal heating options (district heating, and communal heating fed by either biomass boilers or gas-fired CHP) and micro-generation technologies (solar thermal, solar PV and ground and air source heat pumps). The contextual factors affecting behavioural interventions will also be assessed.

2.4 Achieving deep emission cuts from UK housing

The most relevant research that addresses the aims of the present thesis has been carried out through a number of studies that investigate the viability of achieving deep emission cuts from UK housing. This section introduces these studies (2.4.1), and then considers their findings in terms of three key issues they address: the recommended technical interventions to achieve deep emission cuts (2.4.2); the financial implications of refurbishment (2.4.3); contextual factors that affect the achievement of deep emission cuts (2.4.4). Research that specifically addresses social housing is then considered (2.4.5), followed by a discussion of the implications of the reviewed research for this thesis (2.4.6).

Each of the issues addressed is discussed in more detail in chapter 5 of this thesis, where model assumptions used are reported.

2.4.1 Research on deep emission cuts from UK housing

In recent years, a number of model-based studies have specifically addressed the technical feasibility of achieving deep cuts in carbon emissions from housing in the UK (summarised in Table 2.1).

Study	Scope	CO_2 reduction target(s)	Approach and issues considered
BRE (2005)	Existing UK housing stock	60% by 2050	Based upon single "typical dwelling", technical measures only, financial case considered.
Johnston et al. (2005)	Existing UK housing stock	60% by 2050	Based upon two notional dwelling types, technical measures and some demand change.
Boardman et al. (2005a)	Existing UK housing stock	60% by 2050	Highly disaggregated, technical measures and some behaviour change
Boardman (2007)	Existing UK housing stock	80% by 2050	As above, with financial case considered
Natarajan & Levermore (2007)	Existing UK housing stock	50% by 2030, 60% by 2050	Disaggregated, considers technical measures only.
Peacock et al. (2007)	Two of seventy three dwelling variants representing existing UK housing stock	70% reduction by 2030	Technical measures only
WWF (2008)	Existing UK housing stock	80% by 2050	Disaggregated, considers technical measures, behaviour change and financial case
EST (2008b)	Existing UK housing stock	80% by 2050	82 dwelling types, scaled up to UK stock.

Table 2.1 Modelling studies exploring deep emission cuts from UK housing

The three studies carried out in 2005 each claimed that a 60% target could be achieved, although a later review of these three studies by Natarajan and Levermore (2007) found that the interventions studied by Johnston et al. were insufficient to achieve 60% emission reductions. Ten broad refurbishment approaches were also considered in Natarajan and Levermore's research, which found that only one approach could achieve the target of 50% reductions by 2030 and 60% by 2050 (ibid). Peacock et al. (2007) found that 60% reductions could be achieved for both dwelling types considered. However, 70% reductions were not possible through the considered interventions for the dwelling type with relatively high initial emissions (ibid). The WWF research found that 80% reductions could be achieved through the most extensive refurbishment programme considered, if combined with reduced energy demand and grid decarbonisation (WWF 2008). The Energy Saving Trust study found that reductions of 68% could be achieved through a combination of grid decarbonisation, demand reduction and a maximal use of technical interventions, and argued that further cuts in appliance usage would be required to achieve reductions of 80% or beyond (EST 2008b).

Although the methods used and results produced differ slightly between these studies, there is general agreement within the various models considered that to achieve emission reductions beyond 60% in UK housing, an extensive programme of stock improvements is necessary. In each case, this was the most extensive option considered, characterised in the Energy Saving Trust research as “throwing everything at the housing stock” (ibid).

2.4.2 Required technical measures

For each of the studies considered, extensive use of technical measures were required to meet the carbon reduction targets studied, typically including all the low-cost measures discussed in 2.3.1.1, widespread use of more disruptive fabric measures such as solid wall insulation, and extensive use of micro-generation technologies.

The findings differed according to the type and extent of technologies installed. Boardman et al. (2005a) advocated the use of an average of two “low or zero carbon technologies” per home, so that in a 2050 scenario that achieved 60% emission reductions, 60% of dwellings had solar thermal, 30% had solar PV, nearly 40% were heated by microCHP and 20% were heated by community heating. The most successful approach considered by Natarajan and Levermore (2007) involved solar PV, solar thermal or microCHP each being installed in around 45% of homes. The dwelling variants considered by Peacock et al. could only achieve emission reductions of beyond 60% through micro-generation measures, in addition to fabric improvements. The one successful scenario in the BRE research achieved emission reductions beyond 60% by a 50% take-up of solar thermal, solar PV and heat pumps, and through biomass boilers being installed in 25% of centrally heated homes (BRE 2005).

2.4.3 Contextual factors

The majority of the studies considered used scenarios to explore both the refurbishment approaches employed and contextual factors affecting carbon emission reductions. The principal factors explored that are relevant for this research are energy demand levels and the decarbonisation of energy supply (for the electricity grid, and in one case the gas network, through the addition of biomethane). Assumptions for grid decarbonisation relative to the present day by 2050 included a reduction of less than a third (Boardman 2005a), a

50% reduction (BRE 2005) or a 90% reduction by 2050 (EST 2008b). Where changes in energy demand levels were considered, the reductions in demand assumed were relatively low, with the 20% reductions assumed in WWF (2008) representing an upper limit.

Constraints on technical measures were also assumed in each piece of research, in terms of the fraction of UK dwellings for which each measure considered would be applicable, and in terms of concerns for architectural heritage preventing the use of demolition for many dwellings (Boardman 2005a).

2.4.4 Financial implications

Refurbishment to reduce carbon emissions has financial implications in terms of the costs for the parties paying for the work to be done and for householders' fuel bills. The costs of refurbishment were rarely quantified in the studies considered. For Boardman et al. (2005a), this was because of the great uncertainty attached to cost estimates over long timescales, uncertainty about the value that will be attributed to carbon emission reductions in future years, and cost being only one of a number of factors affecting refurbishment decisions (Hinnells 2005).

Financial impacts were assessed in the studies by BRE (2005), WWF (2008) and Boardman (2007). The BRE research put forward a total cost of £55 billion for its successful scenario, indicating an average cost of a little over £2000 per UK dwelling. WWF suggested a total cost of £156 billion for its successful scenario (approximately £6000 per dwelling), or £3.5 billion a year. Boardman put forward a figure of £355 billion (approximately £14,000 per dwelling), based upon total annual spending starting at £10.5 billion in 2008 and declining to £7.5 billion by 2050. Further evidence on the capital costs of refurbishment is reviewed in 9.3.1.

In the studies by WWF and by Boardman, the authors pointed to evidence that improved the case for this significant expenditure. The WWF study made the argument that alongside the cost of measures, the Gross Value Added (GVA) for the UK economy should also be considered (WWF 2008). This concept is intended as a measure of the extra economic activity generated by interventions and was estimated in the study as equating to approximately one third of the installation costs of the measures considered (ibid). However, even where GVA was considered and a financial value was attributed to carbon emission savings, for the only refurbishment approach that achieved 80% emission reductions the net financial impact was negative, with costs outweighing benefits.

Boardman (2007) put the annual refurbishment cost figures of up to £10.5 billion per annum in context by reporting that UK householders spend about £23 billion per annum on home improvements and £18.8 billion a year on fuel bills. The proposed substantial spending on refurbishment is therefore some way short of the total annual spending related to existing UK housing, implying that it could be affordable if the demand existed.

Most of these studies argued that the considered measures would lead to reduced fuel bills for householders, and a reduction or elimination of fuel poverty. However, the inter-relationship between refurbishment spending and resultant fuel bill savings is a crucial issue in this regard. Only the BRE study quantified this, and argued that the overall savings due to its successful refurbishment approach outweighed the overall costs (BRE 2005). This was however largely due to the substantial savings resulting from cost-effective interventions, which outweigh the net increases in expenditure that result from the use of micro-generation measures.

Assessments of cost-effectiveness in the reviewed studies therefore indicated a poor financial case for the more costly and disruptive measures that are the focus of the present research.

2.4.5 The case of social housing

Of the reviewed studies, only Boardman (2007) addresses social housing in some detail, by putting forward policy recommendations for many social homes to be treated using area-based refurbishment, and by recommending that mandatory requirements to improve existing homes should be brought in first for social housing (see 2.6.3).

Little other research has been conducted focussing specifically on achieving deep emission cuts in social housing. An example is a short case study by the Energy Saving Trust focussing on Sanford Housing Co-operative, whose stock consists of a small number of post-war blocks in London (EST 2004b). The research found that emission reductions of 45% could be achieved through low-cost carbon reduction measures, and that reductions of up to 70% could be achieved through the use of micro-generation technologies and reductions in energy demand (ibid). Biomass boilers and solar thermal panels were later installed in these dwellings with the aid of grant funding as part of a package of measures designed to achieve 60% emission reductions (EST 2008c), although whether the target has been met or not in practice has not been reported.

In addition to the Sanford refurbishment, a number of pilot retrofit projects have been carried out by social landlords which have claimed to achieve deep emission cuts (Generation Homes 2007; Green Building Press 2008; Green Building Press 2009), although once more, monitored data to support these claims are either not available or have not been reported. In each case the total cost of refurbishment was of the order of tens of thousands of pounds, although the marginal costs of the carbon reduction measures that formed part of the refurbishment are difficult to separate from other costs.

2.4.6 Implications for this research

The findings from the reviewed studies indicate that extensive refurbishment of UK housing, incorporating fabric improvements and the use of micro-generation technologies, is likely to be required to achieve deep emission cuts. Most of the reviewed studies did little to explore the financial viability of this action. Where it was considered, a financial case for the use of more-expensive measures was not demonstrated. The reviewed studies do not explore how their technical recommendations apply to particular UK housing sectors. Little research exists exploring the viability of achieving deep emission cuts for particular social landlords.

These gaps in existing knowledge create the motivation for the present study, exploring the key issues identified through the reviewed studies — required technical measures, impacts of contextual factors and financial implications — for one case study social landlord.

2.5 Theories for analysing contextual factors

This section seeks to provide a conceptual framework for understanding the contextual factors affecting interventions, by reviewing the contribution from a number of theoretical areas. This includes: the contribution of theories of organisational behaviour (2.5.1) and organisational change (2.5.2) to understanding the context in which social landlords operate; the insights offered by theories on innovation processes (2.5.3); insights from research focussed on the “greening” of organisations (2.5.4). Theories that were explored but not employed are discussed in 2.5.5. The implications for this research are then reported (2.5.6).

2.5.1 Organisational behaviour

Social landlords are organisations, so ideas on how to understand their actions from the field of organisational behaviour are of some relevance. There are many different conceptual frameworks that can be used for analysing organisations, depending upon the aspects of their work that are of interest (Bolman and Deal 1997; Brooks 2003). This research is concerned with contextual issues that affect their behaviour, so literature that focussed on these issues was reviewed.

It is a standard assumption when analysing organisations to make a distinction between the external and internal context (often termed environment) of the organisation (Capon 2000; Brooks 2003). It should be stressed that while of practical use, the internal-external distinction is not a sharp one, and there is a strong inter-relationship between internal and external issues. For example, even a relatively unambiguously external issue, such as an economic downturn, must be "enacted" internally by staff choosing to give the issue attention and changing behaviour in response (Hendry 1996).

The external environment of an organisation can be thought of in terms of its broad general environment and its more immediate operating environment (Worthington and Britton 2003). The former is typically conceptualised through variations of the PEST framework, where political, economic, social and technical factors are taken into account, both on a local, national and global scale (Capon 2000).

The immediate operating environment can be thought of for a business in terms of relationships with the likes of customers, suppliers and competitors (Worthington and Britton 2003). For this research, the organisations and individuals with which a social landlord has relationships are considered using the idea of "stakeholders". A stakeholder in an organisation can be understood as "any group or individual who can affect or is affected by the achievement of the organisation's objectives" (Freeman 1984). For a social landlord such as Peabody, key stakeholders relevant for this study include regulators, Government, residents and its own staff.

The internal environment of an organisation refers to a number of complex and inter-related issues identified in organisational literature, such as an organisation's structure, culture, resources, processes, capabilities, internal politics, history and strategy (Pettigrew et al. 1992; Capon 2000).

Due to the influence of both external and internal contextual issues in affecting action by organisations, this internal-external split will be used when reviewing the impact of contextual factors on social landlord carbon emission interventions in 2.6 and 2.7. It is also used in the analysis of these factors in the scoping interview study (chapter 3) and in the participant observation study (chapter 8).

2.5.2 Organisational change

The branch of organisational literature concerned with organisational change is of particular relevance for this research. This is because a shift towards carrying out extensive carbon reduction refurbishment could entail a potentially significant organisational change for a social landlord, due to the extensive action required (2.4), and the new ways of working involved when carrying out measures that result in energy being supplied directly to residents. Literature from the field has posited that contextual issues play a key role in explaining organisational change, with both external and internal context and the changes in context over time each being crucial issues to consider (Pettigrew 1992; Dawson 2003; Senior and Fleming 2006).

This research has made use of the framework put forward by Pettigrew for researching and analysing organisational change, which identifies three principal issues to focus upon: content, context and process (Pettigrew et al. 1992). *Content* is the "what" of change, referring to the issue being studied. *Context* is the "why" of change, referring to the internal and external context of the organisation that influences the actions that are carried out. *Process* is the "how" of change, referring to the actions and interactions of parties involved in the change process over time (ibid). This approach is founded upon the ontological assumption that "social reality is a dynamic process, constructed by human agents", and that organisational change is typically best explained through an array of intersecting conditions linking context and process, rather than relatively simple individual causes (Pettigrew 1992). This perspective fits well with the philosophical basis underlying the participant observation study put forward in chapter 4.

Literature on organisational change is consistent in terms of classifying contextual issues as either enabling or constraining the issue of change under consideration (Balogun 1998). This perspective on contextual issues fits well with the force field analysis framework put forward by Lewin (1947). This framework is widely advocated in organisational behaviour literature and used by businesses for analysing organisational change situations (Schwering 2003). When applied to organisational change situations, the force field framework considers the change process for a given issue, identifying factors that drive change towards a particular goal, and factors that resist change (Capon 2000). To reach a desired outcome, the balance of the driving and constraining forces must be altered to make that outcome possible (Lewin 1947).

Although rarely recognising Lewin's framework or terminology, literature on energy efficiency issues makes wide use of the concepts of driving and constraining forces, commonly using the terms "drivers" and "barriers". Examples include Jeswani et al. (2007), Schleich and Gruber (2008), and Lowe and Oreszczyn (2008). The term "barriers" has been criticised by some researchers, as it can be interpreted as implying that resistance to change is not legitimate, when in fact the barriers in question may relate to interests or concerns that are of value for reasons not related to energy efficiency (Shove 1998; Blumstein et al. 2000).

For this research, the concepts of content, context and process put forward by Pettigrew have been used to inform the design of the participant observation study. The concepts of driving and restraining contextual factors, or drivers and barriers for short, are employed as useful terminology to describe aspects of Peabody's context, with the proviso that the term "barrier" should not be understood as signifying an issue that is necessarily socially beneficial to overcome when issues other than energy use are also considered.

2.5.3 Innovation

The take-up of carbon reduction technologies amongst social landlords can be usefully viewed as a process of diffusion of innovations. Rogers defines this as "the process by which an innovation is communicated through channels over time among members of a social system" (Rogers 2003). A number of ideas from this field that are of use for the present research are discussed here.

The insight that the take-up of successful technologies tends to follow an s-curve over time, with a slow initial take-up, led by early adopters, followed by rapid adoption and then slow take-up by later adopters (Rogers 2003) is of some relevance. Using this framework, Killip (2008) has observed that the process of carrying out extensive refurbishment of the UK housing stock is still in the research or early adopter phase. As part of this process in the UK, social landlords are likely to play a lead role as early adopters (Boardman 2007; NEA 2009), as is the case for the construction of energy efficient new housing (Housing Corporation 2006b).

Egmond et al. (2006) have applied theories on innovation to research on energy efficiency within Dutch social housing, by distinguishing between early and late adopters of technologies. Early adopters are described as being more likely to encounter institutional barriers which may need to be removed to make interventions viable, and which may be equally applicable to the whole sector. This provides a rationale for studying early adopter organisations so as to identify these barriers (ibid). This has been done in the present thesis, both through the scoping interview study (chapter 3), and through the Peabody case study, as in many ways Peabody fits the description of an early adopter organisation (see chapter 9).

Analysis of the motivations for carrying out interventions can be linked to the five key issues identified by Rogers as affecting their adoption (Rogers 2003): *relative advantage* (the degree to which an innovation is perceived as being better than the idea it supersedes); *compatibility* (the degree to which it is consistent with existing values and needs of potential adopters); *complexity* (the degree to which an innovation is perceived as difficult to understand and use); *trialability* (the degree to which an innovation can be experimented with on a limited basis); *observability* (the degree to which the results of an innovation are observable to others). These concepts are employed in chapter 9 when analysing the contextual factors affecting the take-up of measures.

The long-term view afforded by theories on the take-up of innovation highlights that some drivers and barriers relate to the stage of the diffusion process. For example, concerns around skills and capacity in industry or scepticism about the benefits of new technologies are likely to play a greater role during earlier stages of this process. Given the long timescale under consideration for this research, contextual factors that are of particular interest are those that could have an influence throughout the time-horizon considered. Examples of this include concerns to maintain architectural heritage, which may conflict with wishes to refurbish dwellings, or conflicts between wishes to carry out refurbishment and minimise resident disruption.

A framework put forward by Rouse is useful for conceptualising these issues, where the prospects for an innovation being taken up are judged in terms of its *viability*, *acceptability* and *validity* (Rouse 2003). Within this framework, it is not sufficient to ask if an innovation genuinely solves a given problem (a question of validity), it also needs to be viable (in terms of benefits outweighing costs) and acceptable, when the interests of the stakeholders concerned are considered. These concepts underlie the central approach taken in this research of assessing validity (whether sufficient emission reductions are achieved), viability (whether actions are financially viable for Peabody, and do not require unacceptable trade-offs with other goals) and acceptability (for Peabody staff, residents and other stakeholders). The present thesis therefore differs from most of the studies discussed in 2.4 by considering not just validity, but viability and acceptability.[1]

2.5.4 Greening of organisations

Action on climate change by a social landlord can be understood as an example of "greening" a business, a term used in research literature to indicate action on environmental sustainability or climate change. A developing body of academic literature is addressing this issue from a number of perspectives. Of most relevance for this research are the studies that have investigated contextual factors affecting environmental performance and the motivations for greening.

Both external and internal contextual issues have been identified as motivating greening (Hrebiniak and Joyce 1985; Prakash 2001; Bansal 2003). Legislation is a key external driver in many cases, with many organisations categorised as being compliance-driven, that is, doing just enough to meet the demands of legislators (Worthington and Patton 2005). Other organisations can be said to act "above compliance", with stakeholder influences being identified as principal causes of this behaviour (Prakash 2001; Buysse and Verbeke 2003).

In an extensive investigation into the motivations for corporate greening, Bansal and Roth (2000) outlined three independent motivations: *Legitimation* (consisting of legislation, stakeholder influences and norms for the sector), *Competitiveness*, and *Ecological Responsibility*. A number of internal conditions have also been identified as influencing greening, such as how issues are framed (for example, as opportunities or threats) (Dutton et al. 1983; Janda 1994), the information gathering abilities and power of decision makers (Cebon 1990), and staff values (Bansal 2003).

The literature on greening therefore offers support to the conceptual framework outlined so far of considering external and internal contextual issues. The concepts of compliance and above-compliance behaviour and Bansal and Roth's framework for understanding motivations are used in the analysis of the scoping interview study and the participant observation study.

[1] The term "viability" is used elsewhere in this thesis to refer to the overall feasibility of achieving deep emission cuts, encompassing all three of the issues raised by Rouse, not just the question of whether benefits outweigh costs.

2.5.5 Other theories

A number of potentially useful theoretical perspectives were explored, but not adopted as they did not fit with the main focus of this research. Theories that address how decisions are made in organisations have some relevance (March 1994; Shapira 1997), but were not employed as this research is more concerned with larger-scale contextual issues. A number of different theoretical perspectives can be applied to explain the process of greening (Gladwin 1993), including organisational learning (Huber 1991). These were not applied as a focus on the enabling or constraining influence of contextual factors was sufficient to address the research aims.

Egmond et al. (2005), in an analysis of determinants of action by housing associations on energy conservation, devised a framework of three influencing factors to aid Government policy interventions: predisposing factors (relating to motivation); enabling factors (relating largely to external contextual issues supporting action); reinforcing factors (relating to feedback from external stakeholders). As these issues have each been taken into account by the framework adopted in this research, this categorisation has not been employed.

2.5.6 Implications for this research

Taken together, the insights from these fields provide the conceptual framework used for the study of contextual factors affecting action by Peabody. The interventions carried out are understood as being determined by the inter-relationship between organisational context and processes over time. Contextual issues can be understood as being external or internal to Peabody, and can either act as drivers or barriers to the use of interventions. External context can be understood as relating to both broad societal factors and stakeholder relationships. An assessment of whether deep emission cuts can be achieved requires interventions to be both valid (achieving this goal), viable (in the sense put forward by Rouse (2003), with the perceived benefits outweighing perceived dis-benefits) and acceptable (for all stakeholders concerned). The motivations behind carbon reduction interventions can be usefully analysed using insights from innovation theory and theories from the greening of organisations.

2.6 External contextual factors

Using the framework established above, this section describes external contextual factors that are likely to influence the deployment of carbon reduction interventions by social landlords. Broad contextual factors are reported first (2.6.1), followed by issues relating to relevant stakeholders (2.6.2 to 2.6.5).

2.6.1 Broad contextual factors

Following the PEST framework outlined in section 2.5 above, political, economic, social and technological factors are discussed in turn.

Political issues are likely to have a direct influence on social landlords through either regulation or Government legislation affecting the housing sector, so these issues are addressed in sections 2.6.2 and 2.6.3 below.

Broad economic conditions affect social landlords in a number of ways. Social landlords rely largely upon loans to generate capital, and their financial prospects are therefore influenced by the cost of borrowing, which Peabody staff report as having increased in the past year in the light of the economic downturn. The increased tendency for social landlords to cross-subsidise their socially rented units by sales or market rents of other stock also leaves them vulnerable to reduced income that can result from changes in the housing market. Assumptions on long-term economic prospects also form part of a social landlord's long-term economic plans, where for example, a treasury discount rate that assumes steady economic growth in the UK economy is used to inform investment decisions (see 5.10.3). Changing economic conditions therefore impact upon judgements of the financial viability of stock investment.

Social trends have a significant impact on the nature of domestic energy use (Shove 2009) and the demographics of social housing residents (Housing Corporation 2008b). Demographic issues such as a potentially older resident profile due to an aging population and changes in average household sizes (ibid) will impact upon both energy use in social housing, and the appropriateness of interventions to reduce carbon emissions. Shifts in social norms and values are challenging to predict, but will affect both social housing staff and residents in their thinking and behaviour related to emission reduction interventions.

Technological issues have been largely addressed in section 2.3 of this chapter. Changes in the availability and affordability of emission reduction technologies would have a significant impact on the viability of achieving deep emission cuts in social housing. Conversely, an increased take-up of other energy-using technologies such as appliances, could lead to a continuation of the current trend for increased demand for electricity (NAO 2008).

2.6.2 Stakeholders: Regulators

Social landlords are regulated by the Tenant Services Authority (TSA), which was created in December 2008 after the break-up of the regulatory and funding roles of the Housing Corporation. Social landlords must comply with its regulatory code, which makes three core demands of financial viability, proper governance and proper management (Housing Corporation 2005). Regulation is enforced through inspections by the Audit Commission, annual inspections by the TSA, and annual collection of data by the TSA on key performance indicators (KPIs).

The key regulatory driver for reductions in CO_2 emissions from existing social housing at present is the Decent Homes standard, which sets minimum standards for the state of repair, services, facilities and thermal comfort of existing housing, and which housing associations must meet by 2010 (ODPM 2004). Efforts to meet the standard have been described as the “overriding agenda for social housing landlords” at present (Cooper and Jones 2008). In terms of improvements relevant for energy use, it is triggering the installation of new gas central heating systems and low-cost insulation measures such as loft insulation or cavity-wall insulation. For some landlords, including Peabody, this has led to homes being sold to generate funds to carry out the required works (Peabody Trust 2006). In order to meet the Decent Homes standard, homes must meet the minimum standards set by the Housing Health and Safety Rating System (HHSRS), including achieving minimum standards of thermal comfort. The HHSRS is enforced by local authorities and could be applied to social landlords as a compulsory lever to demand minimum SAP ratings for dwellings or to prevent risks of over-heating, although there is little evidence to date of such action being taken.

Other regulatory drivers impacting on existing stock do not require compulsory action. Social landlords that develop new homes are advised to have a sustainability strategy (Housing Corporation 2003), and 83% do so at present (Sustainable Homes 2007). Average stock SAP ratings must be calculated annually and submitted to the TSA, but there are no formal guidelines for improvements that should be achieved. A consultation on the revision of the Housing Corporation’s assessment procedure put forward a requirement that social landlords work to reduce their “carbon imprint” (Housing Corporation 2007), but a system for monitoring and enforcing this requirement was not proposed.

The regulation of social landlords also gives rise to goals which can conflict with action to reduce carbon emissions. A key example of this is rent restructuring, the process of moving rents in social homes towards target levels set by a Government formula (Walker and Marsh 2003). The resultant inability for social landlords to offset expenditure on energy saving measures by increasing rents has been widely identified as a key barrier impeding the refurbishment of social housing stock (CLG Committee 2007; Hills 2007; UKGBC 2008a).

Social landlords are also currently expected to make substantial savings in their running costs through improving efficiency in their operations (Housing Corporation 2006b), potentially creating a conflict with more sustainable practices when these are more expensive options. Social landlords are also required to minimise the time that void dwellings (homes that are empty between tenancies) are unoccupied. This is likely to conflict with efforts to carry out substantial whole-house refurbishments to dwellings (CLG 2007a; Housing Forum 2009).

With regard to future regulatory changes, the most potentially significant change relates to the proposal that the Decent Homes standard should be superseded by a more demanding sustainability standard for social housing, (SDC 2006a; GLA 2008). Proposals that have been put forward to date include a “Better Neighbourhoods” standard (GLA 2008), that would encourage social landlords to work with Sustainable Homes’ SHIFT framework (Sustainable Homes 2009) for monitoring work on sustainability, and a proposed successor standard that would mandate action for social landlords to achieve minimum energy efficiency standards for their dwellings (Boardman 2007).

2.6.3 Stakeholders: Government

The broad long-term policy framework set by Government for low-carbon retrofitting of existing UK housing is the key influence it can have on social landlords, outside of setting regulatory goals. In a recent review of the prospects for achieving deep emission cuts in existing UK housing, based upon extensive stakeholder consultation, the UK Green Building Council cited the lack of a clear vision from Government as one of three principle barriers to the achievement of this goal (UKGBC 2008a). Survey research on action to improve sustainability in social housing supported this conclusion, with social landlords reporting a lack of Government leadership and lack of incentives to act (Cooper and Jones 2008).

In recent years the policy situation with regard to existing housing refurbishment has been described as a “really serious hiatus” (CLG Committee 2007), with pressures for improvements being “patchy and insufficient” (Foresight 2008). The situation is in a state of some flux at the time of writing, with Government currently developing its Heat and Energy Saving Strategy (DECC 2009a), which addresses long-term policies for reducing emissions from existing housing. This strategy has indicated a significant increase in ambition on existing housing refurbishment, with proposals that by 2030, all UK homes receive whole-house energy efficiency measures, including renewable technologies where appropriate (ibid). The recommendations in the strategy are discussed below in the light of a number of suggested ideas for long-term policy frameworks put forward in recent years (Boardman 2007; EST 2008b; WWF 2008; NEA 2009).

The key recommendation of Boardman (2007) is to introduce mandatory minimum standards for existing housing, so that dwellings with an energy performance certificate (EPC) rating below a minimum standard (initially G, rising to E by 2016) cannot be resold. For social housing, Boardman recommends a second Decent Homes programme, so that all social housing stock achieves a minimum of SAP 80 by 2027. NEA (2009) suggest developing a Code for Sustainable Existing Homes, with ratings tied to existing EPC bands and demanding that where practicable, all homes are at least band C by 2020, with social housing required to achieve band B (equivalent to a minimum of SAP 80). The Energy Saving Trust recommended that refurbishment should be made compulsory at "trigger points" (when improvements are already being carried out in a home), and that carrying out the recommendations in EPCs should be made mandatory from a certain date, such as 2015. WWF outlined several broad areas of action, including mandatory minimum standards and incentivising carbon emission reduction through either a carbon tax or the use of Personal Carbon Allowances.

In response to these proposals, Government has to date rejected calls for setting minimum energy efficiency standards (Green Futures 2008), arguing that mandating action is not appropriate:

> *"Defra's approach to driving change in what we do with our homes is very much built on the voluntary principle – with government exhorting, supporting and providing information rather than laying down the law. It is up to individuals and communities to take action, with the Government providing guidance and removing any regulatory barriers."*
>
> *Defra spokesperson (Green Futures 2008)*

This standpoint is reflected in the Government's HESS consultation, which argues that existing incentives should be sufficient to drive action for the coming years, and states that the role of using regulation to drive action will be explored in 2012 (DECC 2009a).

A second key issue for a long-term framework to address is the question of how refurbishment will be funded. Boardman (2007) proposed extensive Government grant funding to finance the refurbishment of social housing (through area-based refurbishment to address fuel poverty, and a grant-funded second Decent Homes standard). This would be supplemented by partial grant funding to reduce the installation costs of low and zero carbon technologies and the provision of low-interest loans. NEA (2009) called for the creation of an Energy Efficiency Fund of £5 billion per annum, much of which would be used to fund improvements to social housing to meet the recommended minimum standards. WWF (2008) called for increased grant funding and reduced taxes for refurbishment, the use of feed-in tariffs, a renewable heat obligation to incentivise micro-generation, and the provision of low-interest loans.

In the HESS consultation, Government has pledged to act on several of these issues, by bringing in both feed-in tariffs and a renewable heat incentive (DECC 2009a). The area-based grant funded refurbishment proposed by Boardman has been supported through the proposed Community Energy Saving Programme (CESP) which would trial such an approach on a small scale (DECC 2009b). It is unclear whether Government would consider providing grant funding of the order of billions of pounds per annum, as called for by Boardman and NEA, but given the approach to driving change put forward by Defra above, this seems unlikely at present.

2.6.4 Stakeholders: Residents

Residents are key stakeholders for any social landlord, with their satisfaction being a core goal assessed by regulators (Housing Corporation 2005). Social landlords are increasingly required to involve residents in decisions on estate improvements (Housing Corporation 2006a), making their views a critical factor impacting on the acceptability of carbon reduction interventions.

Lack of demand for such interventions from householders is a key barrier constraining the achievement of deep emission cuts from housing (UKGBC 2008). As discussed in 2.2.4, this situation is likely to be even more marked amongst social housing residents. The disruption that stock refurbishment can bring about is an important issue for many householders (Housing Forum 2009) and is something that landlords therefore seek to minimise. This issue has led to refusals of Decent Homes improvements in social homes, particularly by elderly residents (CLG 2007a). Residents' attitudes to technologies may also have an impact on decisions. For example, residents may be mistrustful of any new technologies (CLG 2007a), or have a preference for less-efficient heating systems such as gas fires (Bell and Lowe 2000).

The diversity of tenure types on some social housing estates can create complications for landlords when implementing carbon reduction interventions. For example, installing communal heating on estates with a significant proportion of leaseholders creates the problem of securing participation from those households, and requiring them to make a substantial one-off financial contribution to the works. An example of a project where these issues have been successfully addressed is a communal heating installation by Aberdeen Heat and Power, where Energy Efficiency Commitment funding was used to offset the installation costs for leaseholders (King 2004).

2.6.5 Other stakeholders

2.6.5.1 Local authorities

Local authorities play two key roles in influencing carbon reduction interventions, through devising and implementing spatial planning rules, and through planning and implementing strategic investments in local energy provision.

The planning process has been identified as slowing the diffusion of micro-generation technologies (CLG Committee 2007) and placing potentially significant constraints on the refurbishment of heritage housing stock (Changeworks 2008). This issue creates the need for a judgement on the trade-off between concerns to preserve architectural heritage and concerns to reduce emissions from housing. The present consensus approach, as illustrated by policy recommendations and low-carbon retrofits of heritage dwellings, is to retain the architectural character of heritage dwellings and achieve the greatest emission reductions possible given that constraint (Boardman 2007; Changeworks 2008).

Local authorities can play a strategic role by using their powers to develop decentralised energy infrastructure (DECC 2009a). This is the agenda currently being pursued in London, where the GLA is committed to developing decentralised energy infrastructure (GLA 2007), and has created agencies to support this process. This role is likely to become even stronger if the approach of area-based refurbishment that will be trialled through CESP is to be made mainstream.

2.6.5.2 Industry and utility companies

The lack of capacity in British industry for carrying out an extensive programme of refurbishment of UK housing stock has been identified as a key barrier in a number of recent studies (CLG Committee 2007; Foresight 2008; Killip 2008). This can be related to the early stage in take-up of low-carbon refurbishment to date, discussed in 2.5.3.

The delivery of carbon reduction interventions by social landlords is likely to be carried out to some degree through partnership with utility companies or ESCos (EST 2007a). Partnerships with utilities are likely due to obligations placed upon them by Government to fund carbon reduction refurbishment (currently through the Carbon Emissions Reduction Target (CERT) (Defra 2007e), and through a new mechanism from 2011 (DECC 2009a)). ESCos can take many forms but would typically involve partnership between a social landlord and other organisations to deliver energy services to residents (EST 2007a). An ESCo approach offers a number of potential benefits, such as bringing in outside expertise to manage energy provision, providing support with capital costs, reducing the risks associated with investment in energy infrastructure (at the price of increasing expenditure) and enabling energy use to be managed strategically through one dedicated team (EEBPP 2000).

To date the take-up of an ESCo approach has been limited in social housing, to a large extent due to the low take-up of the low and zero carbon technologies which it is intended to support. As the financial case for such technologies is often marginal at best, the expectation from external partners involved in an ESCo of making a profit from the arrangement reduces the potential take-up of the approach even further. As a relatively new approach, ESCos are also likely to face similar organisational barriers to new technologies in terms of being accepted and adopted by social landlord staff.

2.6.5.3 Other social landlords and support networks

The role identified by Egmond et al. (2005) in reinforcing action by social landlords on energy efficiency is played by a number of organisations in the UK. The Energy Efficiency Partnership for Homes (EEPfH) is a forum that engages housing stakeholders and Government on energy efficiency issues, and disseminates information and research findings to social landlords. A number of landlords are part of its Social Housing group, including Peabody which joined in 2008. The G15 group is a network of London housing associations, of which Peabody is part, which provides a forum for discussion and collaboration on many issues, including action on climate change.

Support on carbon emission reduction is provided to social landlords through a variety of organisations, such as Practical Help and Sustainable Homes (which specifically work with the social housing sector) and the Energy Saving Trust (which works with all housing sectors).

2.7 Internal contextual issues

Existing research has identified a variety of ways in which the internal contextual issues outlined in section 2.5 specifically affect action to reduce carbon emissions in existing social housing. This section begins by reviewing the findings from existing literature on internal factors that are beneficial for achieving carbon emission reductions (2.7.1). Using the framework put forward by Rouse (2.5.3), issues affecting the viability and acceptability of carbon reduction interventions are then explored (2.7.2 and 2.7.3), followed by some implications for the present research (2.7.4).

2.7.1 Beneficial internal factors and "facilitating actions"

Within practitioner literature, there are a number of recommendations put forward to social landlords looking to act successfully on sustainability issues. The factors reported include strategic changes (developing strategies for energy/carbon reduction/etc, and committing to act), structural changes (creating a dedicated post for work on energy management) and achieving support for these goals from the highest level of management (CBA 1999; BRE 2006a; EST 2006).

Personally committed staff that drive action, often dubbed "wilful individuals", have been associated with greater organisational action on climate change issues in the broader not-for profit sector (Defra 2007b), indicating that this is likely to be the case for social landlords. Reliance on individual motivation has however been argued against by literature on sustainability in social housing, stressing the need to move beyond "ad hoc" action to a more strategic approach, where action is specified in the business plan and embedded throughout an organisation's structure, procedures and culture (CBA 1999; Sustainable Homes 2001; Beyond Green 2003).

Research by Egmond et al. (2005) on the work of Dutch housing associations on energy efficiency identified 18 factors impacting on energy conservation work to either a low, medium or high degree. The issues identified that were most connected with strong action were the degree of prioritisation of energy efficiency, a commitment made with a local authority to make improvements, and the presence of a champion on the issue (ibid).

The term “facilitating action” is used in this research to describe any organisational intervention that, whilst not leading to potential reductions in stock carbon emissions in itself, is likely to facilitate action within the organisation to achieve this goal. Examples of such facilitating actions include appointing a dedicated member of staff to work on energy issues, developing a sustainability strategy or using a stock assessment tool such as Ecohomes XB (BRE 2006a). These actions are investigated in the same way as stock interventions through the participant observation study, exploring the process by which they are employed and contextual issues that impact upon them.

2.7.2 Viability

2.7.2.1 Prioritisation

For an intervention to be viable, its perceived benefits should outweigh its perceived costs where all impacts on the organisation are considered (Rouse 1993). This idea relates closely to the concept of prioritisation of carbon reduction as a goal relative to other organisational goals. Recent research has identified that sustainability issues have been given a relatively low priority by social landlords, which often do not perceive them as core to their organisation’s goals (Gillis 2006; Sustainable Homes 2006). In this context, attention is more likely to be focussed upon issues that social landlords are compelled by regulation to act upon, such as those discussed in 2.6.2.

2.7.2.2 Funding and resources

Lack of funding and other internal resources has been identified as a key barrier to action on sustainability by social landlords (Cooper and Jones 2008). In terms of funding, the current situation is that although some degree of grant funding may be available for interventions, refurbishment costs need to be met through social landlords’ existing revenue budgets (Housing Corporation 2008a), which are largely derived from rental income.

Energy efficiency investment in social housing also suffers from the problem of “split incentives”, whereby investment by the landlord leads to fuel bill savings by householders. Rent restructuring legislation prevents these costs being recouped to some degree through rent increases (2.6.2). The likely increase in expenditure coupled with a lack of mechanisms for landlords to recoup costs is therefore a major barrier constraining stock investment for social landlords (ten Donkelaar 2007; Housing Corporation 2008a). Given the current efforts within the sector to achieve substantial expenditure savings through increased efficiency (2.6.2), making significant additional funding available without cutting back on existing planned expenditure is likely to be extremely challenging.

Even if a financial case for refurbishment exists, another potentially significant barrier relates to how this financial case is assessed. In many cases relatively short payback periods of seven years or less have been demanded for carbon reduction technologies, which many relatively capital-intensive interventions are unable to deliver (Element Energy 2008). Where initial capital costs are high, raising sufficient capital could be problematic and act as a barrier (Defra 2004b). This is more likely to be a significant issue for local authority landlords, which are subject to more stringent legislation on borrowing practices, but for UK housing associations such as Peabody, relatively low-cost capital is typically available through capital markets (CLG Committee 2007).

As the discussion in 2.6.5.2 highlighted, staff skills and internal capacity are significant issues relating to organisational resources, which are likely to be addressed to some degree through partnership working with external organisations.

2.7.3 Acceptability

For social landlord staff, the acceptability of carbon reduction interventions is likely to be related to the fit between the carbon reduction agenda and the values of both the organisation and of individual members of staff (Bansal 2003). The increased prominence of climate change and fuel poverty is likely to create broad support for carbon reduction interventions. Acceptability of particular measures is likely to be influenced by staff perceptions and feelings regarding their effectiveness and ease of use (Rogers 2003). Little research exists on attitudes to carbon reduction technologies amongst social housing staff, although negative perceptions on the reliability and acceptability of communal heating have been identified in two studies (COI Communications 2001; EST 2006). Such perceptions could therefore act as a barrier to their take-up by social landlords.

2.7.4 Summary

The evidence reviewed in this section indicates that a number of significant internal barriers exist to the achievement of deep emission cuts. The principal barrier appears to be that interventions to achieve deep emission cuts require significant extra expenditure, which social landlords could struggle to source. Another significant issue is the low internal prioritisation of carbon reduction interventions, which is closely linked to the lack of external drivers discussed in 2.6. A number of organisational interventions which social landlords can carry out to support efforts to reduce stock carbon emissions have been identified. The term “facilitating action” has been introduced to describe them, and will be employed in later analysis.

2.8 Chapter summary

This chapter has established the key concepts that this research explores and has identified existing research that addresses the research aims. The key conclusions are as follows.

- In the light of discussion on climate change targets, two targets for assessing progress on carbon emission reduction in Peabody stock have been put forward: meeting the GLA target of achieving 60% reductions by 2025 and achieving zero carbon emissions by 2030.
- Social landlords can carry out both technical and behavioural interventions to reduce stock carbon emissions. The present thesis will focus on the emission cuts that can be achieved through technical interventions, including analysis of their acceptability and financial viability.
- Based upon a review of possible technical interventions, an approach was put forward of exploring only mature technologies that are likely to be applicable for a significant proportion of Peabody stock (comprising fabric improvements, communal heating and micro-generation technologies).
- A number of theoretical perspectives for exploring contextual factors affecting the viability of carrying out interventions were reviewed. The evidence indicated that both external and internal factors are relevant, and that theories of innovation processes and the greening of organisations could be usefully employed to interpret results.
- Discussion on current contextual factors affecting the take-up of carbon reduction interventions identified many issues, with two of the most important being the lack of a strong drive to act from Government or viable funding mechanisms to carry out interventions.

The implications of these conclusions for the research questions devised for the present research are discussed at the end of chapter 3 after the findings from the scoping interview study are also taken into account.

Chapter 3: Scoping interview study

In addition to the literature review process, the issues affecting carbon reduction refurbishment were explored through a scoping interview study. This was carried out from December 2006 to February 2007, through interviews with staff working in the social housing sector on energy efficiency issues. This chapter reports the motivation and aims for this study (3.1), the methods used to carry it out (3.2), the principal findings (3.3) and a short discussion on these findings and their implications for this research (3.4). Based upon the discussion in this chapter, the findings from the literature review and the research aims set out in chapter 1, the research questions that this thesis will address are then outlined (3.5).

3.1 Motivation and aims

The scoping interview study was carried out as part of a research design process that used an initial pilot study to help finalise the research aims and research questions (Oppenheim 1992; Robson 2003). Its two principal aims were to familiarise the researcher with efforts to reduce CO_2 emissions in the social housing sector and to identify issues affecting the viability of social landlords taking action to reduce stock carbon emissions.

Through the former aim, the study sought to: reduce threats to validity of the research design by ensuring that the researcher was familiar with the key issues faced by social landlords engaged in carbon reduction refurbishment; contextualise Peabody’s work in this area, by contrasting it with the work of other organisations in the sector; identify what carbon reduction interventions were being carried out by some of the most proactive social landlords working on this issue.

Through the latter aim the study sought to: identify what led more proactive social landlords to focus on carbon reduction issues, and the barriers to progress these social landlords face; gather views on what contextual factors need to change to enable the achievement of deep cuts in social housing emissions.

3.2 Methods

3.2.1 Selecting participants

Nine staff from eight English housing associations were interviewed, alongside three other professionals that work with the social housing sector on energy issues. Most interviewees were recruited through previous contact with the researcher at seminars and conferences on sustainability in housing. Sampling was purposeful (Maxwell 2005), with an intentional focus on interviewing staff from organisations that were being relatively proactive on carbon emission reduction issues. A social landlord was understood to be “proactive” here simply if a member of its staff attended an event on energy efficiency, with the assumption that this indicated some degree of organisational commitment on this issue. Staff from proactive social landlords were selected as the study aimed to identify factors that led their organisations to take a lead on environmental issues, and because proactive organisations were more likely to have faced potentially significant external or internal barriers that had yet to be encountered by less-committed organisations (Egmond et al. 2006).

The non-housing association interviewees were from the Housing Corporation (policy manager working on sustainability issues), Practical Help (an organisation providing support on energy efficiency to social landlords) and an energy and sustainability consultant (a member of the Energy Efficiency Partnership for Homes (EEPfH) social housing group). At the time of the interviews, very few professionals in the UK were working specifically on energy efficiency issues in relation to the social housing sector, and the group interviewed contained many of the individuals most actively engaged in this work.

3.2.2 Methods

One-hour meetings were arranged with participants, typically consisting of a 50-minute recorded semi-structured interview, followed by 10 minutes completing a short questionnaire. A semi-structured approach and open-ended questions were used due to the exploratory goals of the research. The questions were designed to address each of the research aims in 3.1 and explore the significance of a number of specific issues identified through prior experience with Peabody or in reviewed literature (CBA 1999; BRE 2006a; Schleich and Gruber 2008). The interview schedule used with housing association staff is shown in Appendix A.

The questionnaire completed at the end of each interview asked interviewees to rank on a 5-point scale the importance of over 20 potential barriers to greenhouse gas emission cuts, identified through the literature above. Participants were then asked if any other significant barriers remained, and if any were offered, to rank their significance. The questionnaire form used and a summary of the results are shown in Appendix B. Using a short questionnaire alongside the qualitative interviews provided a triangulation of methods (Maxwell 2005), countering a potential validity threat of forming conclusions on the importance of barriers based only on interview data.

3.2.3 Analysis

All interviews were transcribed by the researcher, with the exception of two for which the recording was lost due to equipment failure. In these cases, notes taken during and immediately after the interview were used to provide a record. Data from each interview were analysed by identifying the main relevant themes that emerged within a number of a priori categories. These were the external contextual categories outlined in 2.6, internal contextual issues (initially uncategorised except for the two sub-categories of funding and motivation), and actions undertaken (sub-categorised as facilitating actions, technical interventions and behavioural interventions). The more extensive methods of analysis and validity checking used for the participant observation study (4.4.3) were not warranted for this study due to its more limited scope.

The questionnaire results were analysed by attributing a numeric value to the significance of the barriers reported (from 1 to 5), and calculating the average value (the mean) for each barrier for all the interviews (see Appendix B). Consideration was also given to barriers that interviewees chose to add that the questionnaire had not included.

3.3 Results

Results are presented for actions undertaken by housing associations, external contextual issues and internal contextual issues. Where quotes from interviewees are presented to support the account, only the role and a short description of the interviewee's organisation are given by way of identification, so as to preserve the anonymity of respondents.

3.3.1 Actions undertaken

3.3.1.1 Technical interventions

All housing associations were carrying out low-cost carbon reduction measures as part of works to meet the Decent Homes standard. Use of solid wall insulation was rare and was reported as being expensive and highly disruptive. Micro-generation technologies had been installed by all the proactive housing associations, but only for a small number of dwellings in each case, and only with the support of grant funding. Even amongst the most proactive housing associations, whole-house refurbishments to achieve deep emission cuts were not being carried out, and were not seen as economically viable.

3.3.1.2 Behavioural interventions

All housing associations provided energy efficiency advice to residents, and many interviewees also stressed the importance of giving residents guidance on the efficient use of heating controls and micro-generation technologies, if installed. One housing association had given electricity use feedback monitors to a sample of its tenants, at a cost of £35 per household, and reported an average 15% reduction in electricity use as a result.

3.3.1.3 Facilitating actions

The proactive housing associations had each developed an energy (or sustainability) strategy, and in many cases had a dedicated member of staff working on sustainability issues. The extent to which a dedicated staff member was beneficial as a long term solution was however questioned by a number of interviewees.

> *"You might need to start with a focus, but the key to cracking it is making it part of everybody's job, and me existing actually makes that much harder. I get all of the things that relate... anybody sees energy, environment, sustainability, green issues, Jamie Oliver, it lands on my desk. Whereas for another organisation, that's not the case..."*
>
> Sustainability Project Manager, large nationwide housing association

There was no evidence from the interviews of housing associations pursuing alternative management strategies, such as the commonly-recommended approach of developing an ESCo. One interviewee's organisation had participated in the past in a research project leading to recommendations for social landlords on how to set up an ESCo, but despite this, was not using that arrangement itself. The only initiatives of this nature reported by interviewees were relatively small dedicated energy saving funds set up by two of the housing associations.

3.3.2 External context

3.3.2.1 Broad contextual issues

A number of broad contextual issues were addressed by interviewees, including the increased profile of environmental issues and a need to address climate change and energy security.

> *"I think people's eyes are opening to it, and I think the public perception issue is getting much bigger... two years ago environmental issues were once a week on the telly, on the news. Now it's every day, and I think that's good."*
>
> Director of Development, large nationwide housing association
>
> *"And the problem is that if we don't, the whole of the community is much less robust against... you know, global warming effects, Mr Putin turning the gas off…"*
>
> Energy and Sustainability consultant, consultancy

The potential need for a change in the availability and affordability of micro-generation technologies to make deep emission cuts viable was raised by one interviewee.

> *"…unless we get really clever, and we can find really cheap renewable bolt on energy resources… and I've got plans for that. I've got a deal going with the Chinese at the minute to produce cheap wind turbines. And if I can make those £500 a pop instead of £3000 a pop, then a lot of people can have them, we can afford to run our stock…"*
>
> Director of Development, large nationwide housing association

3.3.2.2 Regulators and Government

A strong message emerged from the interviews that action to achieve deep emission cuts needs to be made mandatory if it is to happen. The interviewees saw the housing association sector as highly compliance-driven, implying that if action was not compulsory, most housing associations would not act.

> *"…all the time it's not mandatory, I think not that much. Just a few pioneering housing associations probably, but if all of a sudden the Housing Corporation says it's got to be done, then it will be."*
>
> Innovations and Environmental Manager, medium stock transfer housing association

"Absolutely... I think everyone will put up their hand and say, if you want us to do it, regulate. Tell us to do it, and we'll do it."

Sustainability Project Manager, large nationwide housing association

Where mandatory action was called for, interviewees typically argued that any new standards must then be supported by increased funding in order to be achievable.

"You have to set a standard and then fund that standard. The problem at the moment is sort of toying with some standards, and lots of expectations which aren't actually deliverable because they aren't putting money in the system."

Energy and Sustainability consultant, consultancy

There was a perception amongst many interviewees that new regulations would make action mandatory in the near future. However, the Housing Corporation interviewee stressed the organisation's commitment to light-touch regulation, and argued instead that mandatory action was not on their agenda.

3.3.2.3 Residents

The great importance of resident satisfaction was stressed by many interviewees. Resident demand for stock improvement was rarely reported by interviewees, but increasing support for carbon reduction interventions initiated by landlords was noted, in particular if they were marketed in terms of fuel bill savings.

"Tenants have got their eyes open to it now, if it saves them money, they're very keen. It's the disruption that might be a pain in the arse."

Director of Development, large nationwide housing association

"We're getting more pressure from tenants, not pressure... but cooperation and active support from tenants at the moment."

Director of Asset Management, large housing association

The potentially strong impact of resident demand for stock improvements was demonstrated by the serious concerns a number of interviewees expressed that Energy Performance Certificates (EPCs) could create a high demand for improvements that they were unable to finance.

"We don't want a list of... your property could be zero carbon if you put in thousands of pounds worth of renewable energy... well, yeah, that's great, but we haven't got the money to do that."

Energy and Environmental Services Coordinator, medium housing association

3.3.2.4 Other stakeholders

A number of interviewees reported issues that concern other stakeholders that can be related to the early stage of diffusion of micro-generation in the UK: these included a lack of reliable performance data to inform decisions, a lack of installations to learn from, planning processes slowing down installation, and the UK renewable sector being a "cottage industry". The construction industry was reported by several interviewees as being resistant to change and typically seeking to "do the minimum" with regard to sustainability standards.

3.3.3 Internal context

3.3.3.1 Funding refurbishment

The financial context in which housing associations operate was outlined by a number of interviewees, to highlight the impact that increased action on stock refurbishment would have on their finances.

"…if you increase the specification, that has to be paid for somewhere. And the only place that housing associations get their money from is rents. The maths is quite simple. You increase the standard, rents have to go up. It's as simple as that. So you have to accept either, that that's paid for by residents, or the treasury ends up paying for it through housing benefit. We don't get money from anywhere else. That's a judgement that has to be made at some point."

Sustainability Project Manager, large nationwide housing association

Given this financial context, the lack of a financial case for carbon reduction interventions was identified as a key barrier by most interviewees.

"Solid wall insulation, we've still got problems with that, because there isn't much money around for external cladding or even internal cladding. We've done some on some of them, but not a great deal, because there are no funds within the association to do that on a big scale, and there are no grants to get it."

Energy and Environmental Services Coordinator, medium sized housing association

"Well, money is always an issue, you can't... you know, if anyone says money is not an issue, he's lying, it costs money to do these things... you can have all the knowledge, all the strategies in the world, if there's not money to do it, it'll never get done."

Sustainability Project Manager, Large, nationwide HA

"It's cost really. I know it's the obvious one."

Innovations and Environmental Manager, medium stock transfer housing association

The idea noted in the literature review of partially bridging this funding gap by sharing the financial benefits of refurbishment between tenant and landlord was raised, but the inability to raise rents to achieve this was put forward as a barrier.

"We can't put rents up... but if there was a service charge… say we knew the system would save ten pounds a year, that they'd pay an extra fiver, they've still got a five pound saving, and we get that and put it into helping other residents."

Innovations and Environmental Manager, Medium stock transfer housing association

A theme that emerged in several interviews was that social landlords may look to sell stock that is very costly to bring to a low-carbon standard.

"…those units, for us as a housing business are uneconomic to bring to a future proof state. It'll just cost us too much money, we can't afford it. The value of the property and the rent we'll get from it won't allow us to invest that sort of money. We will sell those units, and hopefully someone else will either invest in them or go green with them."

Director of Development, large nationwide housing association

This points towards an issue that may make carbon reduction refurbishment more challenging in social housing than for other tenure types: the relatively low income social landlords can generate for a given dwelling (due to below-average rent levels), leading to less funds being available for improvements. This issue will be offset to a degree however, due to social landlords being run on a not-for-profit basis.

3.3.3.2 Motivation

The key motivations amongst proactive housing association staff for stock refurbishment were both carbon emission reduction and the reduction of resident fuel bills.

“We do that for two reasons, one because it reduces carbon emissions but two it reduces people's running costs. That is of course a priority for us as a social landlord, so that's what pushes us in that direction.”

Director of Development, large nationwide housing association

“We've got an obligation as a responsible landlord to deliver houses that are affordable to run in terms of general energy costs, and that's becoming more and more an issue.”

Sustainable Development Manager, medium sized housing association

The concern to minimise resident fuel costs was also interpreted as being necessary to ensure future competitiveness by a number of interviewees.

“One of the things that we want to do in the next 12 months is identify the stock that's at risk, at risk for our residents, and at risk for us as a business. If people can't afford to heat their homes, that's not a sustainable household and people aren't going to choose our homes.”

Sustainability Project Manager, large nationwide housing association

A further case for competitiveness was identified where action on sustainability created a positive image of the organisation, which was worthwhile in terms of securing Housing Corporation funding for new developments.

“We've actually got really good PR out of the sustainable, renewable stuff we've done… and if you're responding to [the Housing Corporation] in this sort of way… I suppose we've got a better chance to remain preferred partners of theirs.”

Innovations and Environmental Manager, medium stock transfer housing association

In terms of the three motivations identified by Bansal and Roth (2000) for corporate greening (Ecological responsibility, Legitimation and Competitiveness), the proactive housing associations were therefore largely acting upon ecological responsibility and concerns for competitiveness, alongside the separate ethical concern to provide homes that are affordable to heat. The regulatory aspect of legitimation was not required to provide initial motivation for these organisations to act, but as discussed in 3.3.2.2, was seen as vital for driving action in the wider sector.

3.3.3.3 Other internal issues

Amongst the other internal issues identified, the issue of prioritisation of carbon emission reduction was stressed, which interviewees related to the lack of external pressure to act.

> *“The housing corporation has gone over to what the government calls light touch... which basically means not to interfere so much, not be so prescriptive, and I... my experience of that is that it doesn't work, because all these publicly funded organisations are strapped for cash and they've got lots of stuff landing on them saying you must do this and this, so unless you make it required... what we call in our industry, "What gets measured gets done". If somebody's measuring it, it will get done. If it's not being measured it won't be done.”*
>
> Energy and Sustainability consultant, consultancy

The issue of distinct priorities within housing associations was also reflected by different parts of the organisation having different goals, related to their different motivations and drivers.

> *“It was always a classic argument of the repairs and maintenance side saying we don't want timber windows, we don't care how well-engineered they are, they're timber windows, there's a regime of painting and decorating and all that sort of thing, we really don't want them.”*
>
> Director of Asset Management, large housing association

The key internal drivers for action to reduce emissions identified in the proactive housing associations were motivated members of staff, at both middle management and a senior level, and an organisational commitment to sustainability. In several cases, the driving role of one committed staff member had a significant impact.

> *“I think it's... a large part of it was... <u>I've</u> driven it, I suppose.”*
>
> Innovations and Environmental Manager, medium stock transfer housing association

Regulations requiring housing associations to build new homes to high environmental standards in order to receive Housing Corporation funding (Housing Corporation 2006b) were also found to be a driver, with knowledge on sustainable technologies spreading internally from development departments to asset management staff.

Attitudes from housing association staff towards technological interventions appeared to have a significant impact on their potential deployment.

"You really wouldn't want to overclad those buildings externally, and to do it internally is quite a nightmare... and yeah, if appearance is not an issue you could raise that, but at what cost? We'd have an uproar on our hands."

Director of Asset Management, large housing association

"…barriers... risk, people's perception... it's doing something different, it's not going to work, it's a load of bloody hassle..."

Innovations and Environmental Manager, medium stock transfer housing association

Evidence of how interviewees were framing the issue of carbon reduction refurbishment was gathered by asking for views on the viability of achieving deep emission cuts (of the order of 70% or beyond by 2030) from existing social housing stock. None of the interviewees believed that this was likely to be achieved.

"I can't see how."

Policy manager, Housing Corporation

"Theoretically possible, don't think we're going to actually get there."

Practical Help Manager, energy efficiency consultancy

One interviewee strongly doubted this goal was viable due to the significant expenditure required, but acknowledged that further research was required to identify if this was the case.

"I'll tell you this, if we did have to upgrade all our existing older stock, we'd never do it. We're doomed. We're stuffed. We're never going to be able to afford to do it. We've got to find some other way, I think, and being clever with renewables, and keeping those homes going for another 50 years or whatever 'til eventually they're just too old and too crap, and they get knocked down and redeveloped. So I'm hoping bolt on renewables is the way, but I'm not convinced."

"…whether there's enough cash to do this, I don't know, someone should work that out before they set the targets."

Director of Development, large nationwide housing association

3.3.4 Questionnaire results

The highest ranking barriers emerging from the questionnaire were the same as those identified in the interviews. Prohibitive costs, lack of compulsory action and lack of grant funding were the three main issues highlighted (Appendix B). Constraints on staff resources were also highlighted by the high ranking given to the extra workload involved in applying for grant funding.

Other significant barriers identified by interviewees were often variations on the issues discussed above, corroborating their status as the principal barriers. The issues that interviewees chose to add were: “Money, and impacts on affordability and competitiveness”; “Lack of mandatory need for action”; “Lack of effective regulation by the Housing Corporation”; “Lack of mainstream funding”; “Renewables is a cottage industry – needs more government support”.

3.4 Discussion

The scoping interview study achieved its aim of familiarising the researcher with the social housing sector and the issues faced by social landlords seeking to act on carbon emission reduction. In terms of action undertaken by social landlords, the study indicated that even the most proactive social landlords were not carrying out installations of solid wall insulation, communal heating or micro-generation technologies, largely because of resource constraints. Issues faced by Peabody in terms of funding refurbishment are therefore likely to be representative of issues affecting the broader social housing sector.

External issues, in particular the lack of drivers for substantial refurbishment and the lack of financial support to make it viable, were seen as key barriers. However, the broader financial case for carrying out work to achieve deep emission cuts was not clear, and was identified as an area for further research. A wide range of external and internal barriers were reported, which are contrasted with findings from the Peabody study in chapter 9.

3.5 Research questions

Based upon the aims of this thesis, the findings from the literature review and the scoping interview study findings, the research questions that this thesis will seek to address are put forward below.

Given the research aim of assessing the viability of achieving deep emission cuts in Peabody stock the main research question is:

> *MAIN QUESTION: Can Peabody achieve deep cuts in CO_2 emissions from its existing homes in the period up to 2030?*

The discussion in section 2.3 highlighted the particular technologies that are to be considered in this research, both in isolation and as broad refurbishment approaches. This leads to the question:

> *SUBSIDIARY 1: What technical interventions are required to achieve deep emission cuts in Peabody stock?*

The discussion in sections 2.2, 2.4, 2.6, 2.7 and in this chapter made it clear that contextual factors (such as energy demand levels, and financial support from Government) have a substantial influence both on the emission reductions that can be achieved and the interventions that Peabody are able to carry out. This leads to a second subsidiary research question:

> *SUBSIDIARY 2: What impact do contextual factors — external and internal to Peabody — have on the emission reductions that can be achieved?*

The discussion in sections 2.6, 2.7 and this chapter highlighted funding as a highly significant barrier, which has rarely been addressed in research to date. Based upon this, the following question is put forward:

> *SUBSIDIARY 3: What are the cost implications of stock refurbishment for Peabody and how can these costs be met?*

Section 2.4 made the case for assessing emission reductions that can be achieved against targets, and two targets were put forward. This leads to a parallel research question:

> *PARALLEL 1: Can Peabody meet the GLA's carbon reduction target for 2025? Can Peabody achieve zero net carbon emissions across its stock by 2030?*

The importance of fuel poverty as a twin driver of action to refurbish social housing stock was stressed, implying that this research should also investigate the impact of refurbishment on fuel poverty. This provides the rationale for a second parallel question:

> *PARALLEL 2: What are the impacts on residents' fuel bills and on the extent of fuel poverty arising from interventions to reduce stock carbon emissions?*

The discussion in section 2.4 made it clear that the question of whether there is a financial case for refurbishment can be addressed in a number of ways, considering a social landlord alone, the social landlord and its residents together, or the broader social impacts of refurbishment (where, for example, a price is put upon carbon emission reductions). This leads to a final parallel research question:

PARALLEL 3: Can action by Peabody be justified financially in terms of: Peabody being better off overall? Peabody and its residents being better off overall? Society being better off overall?

Through addressing these questions for the particular case of Peabody, this research seeks to make an original contribution to knowledge by extending and deepening knowledge of the issues affecting the viability of achieving deep emission cuts in social housing.

Chapter 4: Methodology

This chapter describes the methodology used to answer the research questions put forward in chapter 3. The philosophical assumptions underlying this thesis are first introduced (4.1), followed by a description of the overall research design (4.2). The research methods used for the two inter-related studies carried out are then described (4.3 and 4.4), followed by a chapter summary (4.5).

4.1 Philosophical assumptions

Any research methodology is guided by philosophical assumptions regarding the nature of reality (i.e. ontology) and assumptions regarding the extent to which reality can be known (i.e. epistemology). Ontological, epistemological and methodological standpoints have typically been grouped together by academic researchers into research paradigms, a “set of basic beliefs that guide action” (Creswell 2007). Paradigms can be conceived of as occupying different points on a spectrum ranging from positivism to social-constructivism (Guba and Lincoln 1994). Positivism is a paradigm associated with scientific research, entailing a belief in an objective reality, an ideal of a detached, impartial researcher, and a methodology of rigorously testing prior hypotheses, typically using quantitative methods. Social-constructivism, a common paradigm in social research, emphasises the subjective nature of reality and sees the construction of meaning as being situation and context specific, and favours qualitative methods. A paradigm between these extremes is that of post-positivism (Creswell 2007), which retains the ideals of positivism, whilst acknowledging issues raised by the likes of social-constructivists such as the role of subjectivity in the research process. The paradigm differs from social-constructivism in that subjectivity is seen as a validity threat that should be minimised, rather than an inevitable part of the research process that should be openly acknowledged (ibid).

A distinct paradigm, pragmatism, which does not fit easily within the positivism-constructivism spectrum, has been used to guide this research. This paradigm breaks the traditional association between worldview and methodology, taking the stance that methodology should be selected first and foremost based upon the research questions and the specific situation at hand (ibid). A pragmatic stance enables a variety of research methods to be employed, and as a result, is commonly associated with mixed-methods studies, which combine both qualitative and quantitative methods (Tashakkori and Teddlie 1998; Creswell 2007).

In the present thesis, the distinct issues and questions addressed by the two studies have led to two distinct packages of methods being employed. Despite the over-arching pragmatist stance employed, the philosophical assumptions underlying these studies can be usefully explained with reference to the spectrum of research paradigms outlined above.

The Peabody Energy Model (PEM) study, which involved the development of a quantitative energy model, is informed by an ontology and epistemology that fits with the post-positivist paradigm. The reality of the situation at hand (energy use, carbon emissions, expenditure, etc) is seen as objective and independent of the researcher. Knowledge of this situation is therefore possible but constrained by limits in theoretical understanding or lack of supporting data.

The participant observation study explores the actions and views of Peabody staff. The reality of this situation is not observer-independent, due to the necessarily participatory role played by the researcher, influencing both staff views and action, making a post-positivist framework inappropriate. Instead, the study was informed by a rationale that sits somewhere between post-positivism and social-constructivism, recognising the views expressed by Peabody staff as subjective and context-dependent. In terms of ontology and epistemology, this study follows the approach taken by Wall (2006), recognising that even though we cannot be certain about the existence or endurance of reported mental states such as attitudes or opinions, as they cannot be accessed directly, they are nevertheless “a useful device” that are likely to relate to actions in the real world. This study therefore reports staff views in realist language (e.g. “The chief executive thought it was too expensive.”) and infers implications for action based upon the views reported, whilst recognising that the reality of such claims is still open to doubt.

4.2 Overview of the research design

4.2.1 A design framework

The overall research design was developed using a framework put forward by Maxwell (2005) where research questions, goals, methods, the conceptual framework underlying the research, and checks for validity are considered as an integrated whole (Figure 4.1).

Within Maxwell's framework, the upper and lower triangles illustrated in Figure 4.1 are intended to each be closely integrated. The integration of goals, research questions and the conceptual framework underlying this research was the focus of chapters 2 and 3 of this thesis. The integration of research questions, methods and validity to devise a research methodology is the focus of the present chapter.

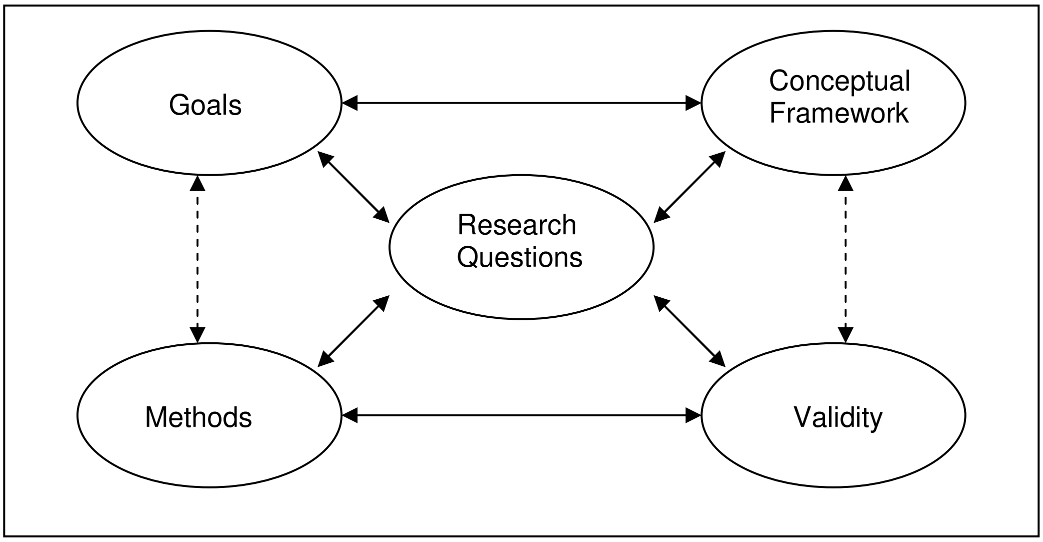

Figure 4.1 An interactive model of research design, after Maxwell (2005)

Goals, as defined by Maxwell, represent a broader concept than the academic research aims detailed previously, and include other goals such as the personal goals of the researcher to develop new knowledge and skills and the practical goals for the project. The latter consideration was of particular significance for this research, as useful practical outcomes were an important requirement to ensure the collaboration of the project partner, Peabody. The research aims were therefore arrived at in close consultation with Peabody staff, so that they were of both practical and academic interest.

4.2.2 Methods

The methods used for a piece of research can be understood as the procedures, tools and techniques used to generate and analyse data (Schwandt 2001). This is distinct from the research methodology, which can be understood as the overarching approach used, which is realised through the particular methods applied.

In the present thesis, the overall methodology used comprises two inter-related studies. In the quantitative study, key issues of interest such as Peabody stock carbon emissions and stock refurbishment costs were quantified through the development of the Peabody Energy

Model. In the participant observation study, contextual factors affecting action by Peabody were explored through interaction with Peabody staff during the research period.

This approach was arrived at through considering the methodological implications of answering the main research question: "C*an Peabody achieve deep cuts in CO_2 emissions from its existing homes in the period up to 2030?*". This question implies a need to quantify emissions from Peabody homes over future years based upon Peabody interventions, which in turn implies a methodology of modelling Peabody stock emissions – combining inputs in terms of energy demand and technologies into outputs in terms of emissions. As viability for Peabody is broader than technical viability, as chapter 2 established, this question also implies a need to assess the impacts of broader factors outside of Peabody's control and the acceptability of any recommended interventions. The primary judges of this acceptability will be Peabody staff themselves, based upon their experiences with and attitudes towards the considered interventions and input from other stakeholders such as residents. This implies a need for a second study to collect data from Peabody on these issues. The rationale for using a participant observation approach for this is discussed in 4.4.

Taken together, the combined approach of the PEM study and the participant observation study allows both technical viability and broader acceptability to be explored, providing an answer to the main research question. This combined approach was also used to address the subsidiary and parallel research questions. The way this was achieved is described in section 4.3 and chapter 5 for the PEM study, and in section 4.4 for the participant observation study.

4.2.3 Validity

A concern for validity creates the need to consider how the findings and conclusions from the research could potentially be doubtful or wrong (Maxwell 2005). To ensure that research findings are reliable and credible, a research design should seek to address specific validity threats (ibid). Validity threats and strategies used to mitigate them are described for each study in sections 4.3 and 4.4 respectively.

4.2.4 Ethics

The ethical issues relating to this research relate both to Peabody as an organisation and the individual staff and residents that participated in this research.

For Peabody as an organisation, an ethical requirement that made continued access to the organisation possible was that the relationship between the researcher and Peabody should be reciprocal, a common concern in longitudinal case study research (Pettigrew 1990). This was achieved through devising research aims in collaboration with Peabody, and by maintaining a co-operative and supportive relationship with staff. This relationship was maintained by responding to requests for information and providing ideas on carbon reduction interventions when required, meaning that this research would inevitably impact upon Peabody's work on carbon reduction.

In line with the approach taken by Pettigrew (ibid), no research findings were made public without prior agreement from Peabody staff. When sensitive information was shared with the researcher, this was kept confidential when requested and stored securely on the researcher's computer at De Montfort University. With regard to individual research participants, Peabody staff were told prior to interviews that any research outputs would not refer to their name or position so as to ensure anonymity. Where residents were surveyed, anonymity was again guaranteed.

In a study motivated primarily by carbon emission reduction, it is perhaps also a relevant ethical issue to consider the carbon emissions associated with the research process itself. Based upon monitoring of journeys undertaken for this research and apportioning energy use in the building where the researcher is based amongst its users from April 2006 until May 2009, an estimated 2.6 tonnes of CO_2 can be directly attributed to the conduct of the present research. If the findings can contribute to emission savings beyond this figure, then there is a good case for this research being ethically justified from an emission reduction perspective.

4.2.5 Generalisation

This research comprises an in-depth study of a single case-study organisation, and yet one of its desired outcomes, expressed in section 1.1, is to arrive at conclusions that may be of relevance to the social housing sector as a whole. This raises the question about the extent to which generalisation from this research is valid.

A useful distinction to consider at this point is that between generic and particularistic research questions (Maxwell 2005). For the issues studied in this research, a generic question would be concerned with the general issue of reducing emissions from social housing as a whole. This contrasts with the particularistic research questions used for this research, which focus upon the particular case of Peabody alone. This research is therefore primarily concerned with Peabody, and should not be understood as being solely a means to generate findings for the broader social housing sector. If that was the primary goal of this research, a different research design involving input from many more social landlords would have been likely to have been required.

In terms of generalisation, case study research can not be validly used to generalise up to a wider population in the same way that is possible, for example, through a randomly chosen population in survey research. However, case study research can provide “generalisations to theory”, meaning theoretical explanations of the data observed which may also be applicable in similar cases where similar conditions prevail (Yin 2003). An example of such a generalisation could be that funding refurbishment by sharing financial benefits with residents is challenging due to regulation preventing Peabody (and other social landlords) from increasing rents. Such generalisations are likely to be possible in this research, due to the similar conditions under which social landlords operate. The validity of such conclusions can be supported through evidence from the scoping interview study which identified the actions undertaken and contextual factors affecting other social landlords.

The single case study approach used in this research is typically viewed as inferior to a multiple case-study approach from the perspective of generalising to other cases (Harrigan 1983; Yin 2003). A single case study can however be of great value where the case in question is unique, typical, or potentially highly revelatory due to the researcher having access to a previously inaccessible situation (Yin 2003). The latter rationale is of particular relevance for this research, where the researcher was granted rare and extensive access to the staff, documents and internal processes of a social landlord over a three-year period. This level of access has presented a unique opportunity to develop a deeper understanding of the issues affecting carbon reduction refurbishment.

4.3 Quantitative study: The Peabody Energy Model

4.3.1 Aims

The PEM study aimed to address each of the research questions put forward in chapter 3, by quantifying the impact of refurbishment approaches and particular interventions on carbon emissions, resident fuel costs, fuel poverty levels and refurbishment costs. The model results also established issues to be explored through the participant observation study discussed in section 4.4.

4.3.2 Methods

The PEM quantifies energy use, carbon emissions and resident fuel costs from the base year 2006 (the base year for the London Climate Change Action Plan) to 2030. Refurbishment-related costs are considered from the period 2011 to 2030. Calculations are carried out on an estate by estate and year by year basis. It is assumed that Peabody's current planned work to meet the Decent Homes standard continues to 2010. From 2011, distinct approaches to refurbishment are modelled, ranging from a base approach of current planned levels of refurbishment, through to approaches making significant use of micro-generation, communal heating and solid wall insulation. From the perspective of obsolescence (introduced in 2.2.3), it is assumed that Peabody dwellings continue to be used as in the present day (that is, they do not become obsolete from the perspective of tenants' needs), and that the technologies whose installation is studied do not become obsolete during their functional life.

Developing the PEM required an extensive number of decisions and assumptions to be made, which were then carried out by creating a model using the spreadsheet software Microsoft Excel. In addition to the assumptions relating to the model itself, four scenarios were specified which changed a number of model inputs. A method for applying the GLA's carbon reduction target to Peabody was also devised. Chapter 5 of this thesis describes these methods and assumptions in detail.

4.3.3 Analysis

Outputs from the PEM were used to address each of the study's research questions. The main research question, on the viability of achieving deep emission cuts, was addressed using outputs on average stock carbon emissions up to 2030.

The first subsidiary research question ("*What technical interventions are required to achieve deep emission cuts in Peabody stock?*") was assessed by initially considering four broad refurbishment approaches. The impacts on emission cuts of individual technologies, such as solar PV or communal biomass boilers, were then considered by quantifying the impact of their addition to a refurbishment approach.

The second subsidiary research question ("*What impact do contextual factors — external and internal to Peabody — have on the emission reductions that can be achieved?*") was addressed both by the PEM study and the participant observation study. The PEM study explored uncertainty about future socio-economic conditions on model results by specifying four scenarios under which the refurbishment strategies considered could take place. These scenarios affect a number of model inputs such as resident energy demand and the availability of low-carbon energy supplies. The influence of contextual factors such as planning constraints was also explored. For example, the change in model outputs was identified where constraints on refurbishment in conservation areas were removed, allowing further installations of micro-generation technologies or external wall insulation.

Subsidiary question three ("*What are the cost implications of stock refurbishment for Peabody and how can these costs be met?*") was explored through the model by calculating net annual expenditure due to each refurbishment approach considered, and contrasting more-extensive refurbishment approaches to Peabody's current planned strategy. The question of how any extra costs could be met was explored through the model by identifying the sales of stock or rent increases that would be required to make refurbishment cost-effective. Possible funding approaches were also explored through staff interviews in the second study.

Parallel question one ("*Can Peabody meet the GLA's carbon reduction target for 2025? Can Peabody achieve zero net carbon emissions across its stock by 2030?*") was addressed using the model by identifying scenarios and refurbishment approaches that allowed each goal to be achieved.

The impacts on residents' fuel bills and the extent of fuel poverty arising from interventions to reduce stock carbon emissions (parallel question two) was quantified using the model, with assumptions on fuel use and expenditure being translated into figures for fuel bills for residents. By combining this data with assumptions on household income, estimates of fuel poverty levels on Peabody estates were made.

Finally, parallel question three ("Can action by Peabody be justified financially in terms of: Peabody being better off overall? Peabody and its residents being better off overall? Society being better off overall?") was addressed using the model by considering the Net Present Value (NPV) of refurbishment approaches (defined and described in section 5.10). NPV is traditionally calculated for an organisation alone, but by extending its scope to treat Peabody and its residents together, the extent to which they are better off overall can be identified. By then attributing a monetary value to savings in carbon emissions, an economic assessment of whether society is better off overall can be carried out.

4.3.4 Validity

The two key threats to validity for the PEM study relate to either the assumptions used in the model being invalid, or to errors in its implementation (through a number of related spreadsheet files).

Model assumptions take the form of theoretical assumptions (such as the equations used to estimate fuel poverty or hot water demand) and the values used for variables (boiler replacement costs, fuel costs, etc.). For the former issue, this research used an established methodology of combining an energy use model with NPV analysis already used in previous research (Verbeeck and Hens 2005; WWF 2008; Dwyer forthcoming). The broad approach and the specific method used for calculating NPV were developed in partnership with Peabody, ensuring its relevance and validity from Peabody's perspective. The particular equations used in the model were based upon existing peer-reviewed research wherever possible. Model assumptions were checked both by the supervision team and externally by an energy efficiency consultant contracted by Peabody in December 2008 to undertake a peer review of the model methodology.

The values for variables used were based upon Peabody experience where possible, or recent literature on carbon reduction refurbishment where not. Costs for fabric improvements for dwellings were checked in 2008 with Peabody's cost consultants for reliability, and increased from previous estimates as a result. Uncertainty about these assumptions was addressed by carrying out sensitivity analysis, through which the impact of changing the values of variables on model outputs was explored.

An important validity check that is commonly employed in model-based research is to compare model outputs to real data. This has typically been very challenging to achieve for research on energy use in UK housing, due to the poor availability of data on actual energy usage (Oreszczyn and Lowe 2004). A number of possible methods for achieving this for Peabody stock were actively considered for this research. These included contacting several hundred Peabody homes to obtain permission to secure energy use data from utility companies; surveying Peabody residents on their fuel expenditure; identifying fuel use on communally heated estates from Peabody fuel bills; installing equipment to monitor electricity use in blocks on Peabody estates. None of these methods could be carried out in practice. Although data from a relatively small sample of dwellings could have been collected through a survey of residents, this was viewed as being of little use for validation or for prompting model improvements due to the significant variability in domestic energy demand between households (Sonderegger 1978; Gram-Hanssen and Peterson 2004; Hong et al. 2006; Baker 2007). In the absence of such data, the results were sense-checked (ensuring that model outputs were of an appropriate order of magnitude) against statistics for average energy use in the UK.

Potential spreadsheet errors are a significant threat to validity for this research, given that for large spreadsheets it is highly unlikely that no errors at all will be present (Panko 2008). This risk was countered initially by extensive manual checking by the researcher. This included: sense-checking of model outputs (i.e. ensuring that all outputs were of a reasonable order of magnitude); going through the main model spreadsheet twice after completion to check all equations; ensuring that changing assumptions (such as refurbishment approach, or fuel costs) had an explicable effect on model outputs. A member of the supervisory team also spent three working days independently checking the model spreadsheet for errors or inconsistencies, and no further errors were found. Such external auditing of spreadsheets has been found to typically identify around 50% of errors present (ibid). Despite these checks, there remains a significant risk that some errors may remain in the final model spreadsheets. However, due to the sense-checking of outputs and the fact that those errors discovered as part of the checking process did not have a significant impact on the overall model findings, it appears that the key findings emerging from the PEM study can be trusted with a satisfactory degree of confidence.

4.4 Second Study: Contextual factors affecting Peabody

4.4.1 Aims

The second study aimed to identify significant contextual factors, both internal and external to Peabody, which affect the viability of carrying out carbon reduction interventions. Using the terminology of the framework put forward in chapter 2, this study aimed to identify the principal barriers affecting Peabody and to identify drivers that would be required for deep emission cuts to be achieved.

4.4.2 Methods and rationale

4.4.2.1 Participant observation

The over-arching method used to achieve the above aims was participant observation. Participant observation involves a researcher simultaneously observing and participating in the social situation being studied. It is typically carried out using a number of methods, including direct observation, interviewing, document analysis, reflection, analysis, and interpretation (Schwandt 2001). This method has been advocated by Pettigrew for studies seeking to explore the context and process of action by organisations over time, as is the case in the present research (Pettigrew 1992).

A key method used was the semi-structured interview. Interviews are a commonly-used method in social research, with their application ranging from highly structured interviews, where questions have a fixed wording, to entirely unstructured interviews addressing broad research themes. A semi-structured approach was taken in this research to address specific issues identified as important, whilst retaining flexibility so that other relevant themes could emerge.

As discussed in 4.2.4, a degree of participation was inevitable for this study, due to the need to secure the support of the case-study organisation. However, the intensive long-term involvement required for this approach also brings benefits in terms of allowing the researcher to develop a deeper understanding of the relevant issues in the research environment (Maxwell 2005).

4.4.2.2 Data collection

Data collection at Peabody was guided by the over-arching framework put forward by Pettigrew et al. (1992) discussed in section 2.5.2 and sought to identify:

- actions being undertaken or considered (interventions and facilitating actions)
- the process behind action on carbon reduction (how and when actions were undertaken)
- contextual factors affecting actions.

The methods used to collect this data included semi-structured interviews and informal opportunistic conversations with staff, attendance at meetings, attendance at resident events and analysis of relevant documents. Many opportunities for data collection were identified and taken up responsively according to developments at Peabody. Data collection therefore reflected the necessarily “messy” nature of organisational research that has been stressed by Bryman (1988), who emphasised issues such as the opportunistic nature of much data collection, the important role of good fortune, the impact of available resources on what is feasible and the ongoing challenge of maintaining access. For this research, resources did not prove to be a significant constraint, and access was successfully maintained as a result of a positive and reciprocal working relationship with Peabody staff.

There was a long-term engagement with Peabody, with regular contact from July 2006 until April 2009. During this period, the researcher made 36 visits to Peabody, and on days of visits was based in its Asset Management department. Research issues were discussed in 52 semi-structured interviews and informal discussions, involving 25 Peabody staff in all. In addition, the researcher was invited to participate in 15 internal meetings relevant to this research, 2 events for Peabody residents and at 5 meetings with external organisations. The researcher also had extensive contact over email and telephone with Peabody staff and was granted full access to relevant internal documents by Peabody. A record of the visits to Peabody made during this research is shown in Appendix C.

At the start of the research period, the current action being undertaken by Peabody to achieve carbon emission reductions was identified through meetings and interviews with relevant staff. Action was defined as technical interventions, behavioural interventions and facilitating actions, following the framework put forward in chapter 2. When action was undertaken, staff were interviewed on how it came to happen, on any contextual issues affecting that action and on its practical outcomes. Ongoing action was monitored through regular meetings with relevant staff during the research period. These meetings were carried out with six Peabody staff whose responsibilities related to stock energy use. These staff can be described as “key informants” for this study.

As the Peabody Energy Model was developed, interim research findings were presented to Peabody staff and residents on a number of occasions from late 2007 to early 2009. Views on the viability of the considered refurbishment measures were collected from staff and residents during these presentations. At the end of the research period, four of the six key informants introduced above were still working at Peabody. Three of these four staff members (those having the most detailed knowledge on relevant issues for this research) were interviewed specifically on contextual issues affecting recommended actions from the PEM study in a 90 minute interview. The interview schedule for this meeting is given in Appendix D.

All meetings and conversations with Peabody staff were documented through case notes taken during the interaction, and written up as soon as possible afterwards. It was rarely possible to record conversations so that verbatim comments could be accurately recorded, either due to permission not being granted or the discussion taking place in an informal context. Recording was however done on four occasions: for a meeting on Peabody's sustainability strategy in January 2007; a meeting with the chief executive in February 2007; a meeting with a key informant from the development department in February 2007; the final interview with three key informants in February 2009. In these cases, the recording was transcribed by the researcher prior to analysis.

4.4.2.3 Resident survey

A survey was also carried out to collect data from residents to support the assumptions used for the PEM. This was an opportunistic piece of data collection, which took advantage of the researcher's attendance at the Peabody residents' conference in summer 2007 to rapidly collect data from Peabody residents. The survey was carried out to inform the development of the PEM, by overcoming specific gaps in knowledge on the extent of use of energy efficient lighting in Peabody homes and on patterns of use of heating systems by Peabody residents. This survey was trialled in advance with a fellow researcher to check the intelligibility and clarity of questions. Approximately 25% of the residents attending completed the survey, providing 58 responses in all. The survey used and its results are shown in Appendix E.

4.4.2.4 Methods not employed

A more formal focus group approach could have been a beneficial alternative to the final interview with three key informants, allowing new ideas to potentially emerge from the interaction between interviewees (Krueger and Casey 2000). This approach was actively explored, but was rejected as it did not appear feasible to secure the participation of sufficient staff for a dedicated meeting that was primarily of use for this research, rather than for Peabody. The final interview did however achieve many of the benefits of a focus group. By bringing together the three staff with the greatest expertise on the issues studied, it enabled a more detailed discussion to take place and gave the interviewees the opportunity to respond to other points of view and reach a consensus on some issues.

Quantitative methods could also have been used, for example to rank the barriers identified or the importance of necessary policy changes, as was the case in the scoping interview study. For this study, such an approach was deemed to be unnecessary, as the extensive engagement with Peabody staff and questions asked in the final interview on the relative importance of issues discussed made the principal issues of concern clearly apparent to the researcher.

4.4.3 Analysis

The data generated for analysis by the methods described above comprised 4 interview transcripts, notes from 68 meetings and discussions, 11 internal documents, 27 relevant emails and 2 external documents produced by Peabody.

The goal of data analysis was to reduce this data to a smaller number of concepts and issues which address this study's research questions. This was done using a standard approach in qualitative research of coding the data, meaning that particular passages were identified with particular themes and concepts. Analysis was carried out using the data analysis software NVIVO, which enables passages of text to be coded as part of a hierarchically-organised coding template.

Approaches to coding vary from attempting to fit data within pre-existing a priori categories, to the approach taken by researchers using grounded theory, where codes are derived from the data alone (Miles and Huberman 1994). This research makes use of a number of existing theories discussed in chapter 2, but is also exploratory and open to new findings, so coding made use of both a priori codes and codes emerging from the data. Analysis was based upon King's Template Analysis framework, as this offers a well-defined method for coding and analysing qualitative data (King 2009).

The use of Template Analysis for this study is summarised by the following seven steps, based upon those put forward by King (2009).

Step one: Identify a priori themes and codes

For a given text, themes are perceptions or ideas identified by the researcher that are relevant for the research questions being addressed, and codes are the labels attached to them. For this research, the a priori codes used were based upon the framework put forward in chapter 2.

Step two: Familiarisation with data

In the Template Analysis framework, this step involves transcription of the interview data. For this research, this step involves two actions: writing up meeting notes and transcribing interviews (done as soon as possible after data collection), and identifying all of the documents which were to be analysed and uploading them into the NVIVO software package.

Step three: Initial coding of data

This step involves coding passages of a subset of the data to fit either within the initial a priori codes, or within new codes where required. Passages were coded as belonging to several distinct themes where this was seen to be appropriate.

Step four: Initial template

The initial coding developed was then refined, so that all codes were included in a hierarchical template structure. Any a priori codes which did not fit with themes emerging from the data were discarded at this stage. The resultant initial template is shown in Appendix F.

Step five: Validate template

This stage is carried out to mitigate the potential threat to validity of researcher bias, by seeking to check inter-coder reliability. A colleague with a research background in domestic energy use and experience of working with NVIVO software was invited to code a selection of the data so that a comparison between the coding decisions could be made. Agreement was measured using a formula put forward by Miles and Huberman (1994):

% reliability = agreements / (agreements + disagreements) x 100

This exercise revealed an initial agreement of 70%, which rose to 85% when errors of understanding were corrected, and complete agreement (leading to changes in the original coding) after discussion on the remaining discrepancies. Feedback was also given on template structure and the names of codes which influenced the development of the template.

Step six: Develop template

The initial template was then developed by re-examining and coding all data. Changes were made to the template where: a new code was required; a code was abandoned; a code was moved within the hierarchy of codes to provide a better fit with the data. Further feedback from the colleague that carried out the coding check in step five was used as part of this process, leading to the development of the final template (shown in Appendix G).

Step seven: Interpret and write-up findings

The final template was then used to interpret and write-up the research findings, providing the structure for chapter 8 of this thesis.

4.4.4 Validity

The key threats to validity for this study relate to: the accuracy of the account of actions undertaken and issues reported by Peabody staff; taking appropriate account of the influence of this research on actions at Peabody; conclusions on the relative importance of issues identified; conclusions on the broader policy implications of findings. A number of the strategies put forward by Maxwell (2005) to mitigate specific validity threats in qualitative studies were employed to address these threats (shown below in italics)

Intensive long-term involvement in the research setting can allow ideas to be developed and tested over time, and a wide variety of data supporting an account to be collected. This was achieved in this study through frequent contact with Peabody, including many visits and days based in their office, and discussion with staff on key research aims on many occasions over a 3-year period.

Respondent validation involves soliciting feedback on data and conclusions. This was achieved through presentations to Peabody staff and residents on research findings, and collaboration with key informants on the presentation of research findings to an external audience. The account presented in chapter 8 was also checked with two members of Peabody staff for accuracy, leading to a number of revisions.

Triangulation involves collecting information on the same issue from a variety of sources and from a variety of individuals. In this research this was achieved through interviewing many different members of staff on the issues considered on several occasions, and supplementing this data with evidence from informal conversations and internal documents where available.

Comparison with other similar contexts is a useful check for validity when seeking to identify implications from this research for the social housing sector. This was achieved through the initial scoping interview study, asking Peabody staff about the work being carried out by other social landlords, attending relevant events on carbon reduction refurbishment and regularly checking practitioner journals.

Maxwell (2005) also identifies researcher bias and reactivity (the influence of the researcher on the research environment) as potential threats to validity. Researcher bias was addressed by checking inter-coder reliability and receiving feedback from Peabody staff on research outputs. The issue of reactivity potentially affects the validity of generalising from the Peabody experience. Researcher influence on Peabody was a necessary and desirable part of the research process, but creates a need for an honest account of the influence of the research on the behaviour of the case-study organisation. Influences of the researcher on action at Peabody were therefore recorded throughout the study and are reported in chapter 8 of this thesis.

4.5 Summary

The research design and methodology used have been presented. This comprises two inter-related studies: a quantitative study, for which the Peabody Energy Model was developed to quantify energy use, carbon emissions, resident fuel costs, and the financial impacts of refurbishment; a participant observation study, which used engagement with Peabody staff over a 3-year period to identify contextual factors affecting action by Peabody to reduce stock carbon emissions.

The following chapter explains in more depth the assumptions and approaches used to develop the Peabody Energy Model, with the model results being reported in chapters 6 and 7. The results of the qualitative study on contextual factors are reported in chapter 8.

Chapter 5: The Peabody Energy Model

In this chapter the methods used to develop the Peabody Energy Model and the rationale behind them are described. The over-arching approach used to model energy use is first put forward (5.1), followed by a description of the four scenarios used to consider possible future socio-economic conditions (5.2). The specific methods and assumptions used are described in sections 5.3 to 5.11. The issues addressed in each section are illustrated in Figure 5.1, which shows the structure of the model and its principal assumptions and outputs.

The use of sensitivity analysis to check the validity of model outputs is described in 5.12. An explanation on how the carbon reduction targets discussed in 2.1 can be applied to Peabody stock is given in 5.13.

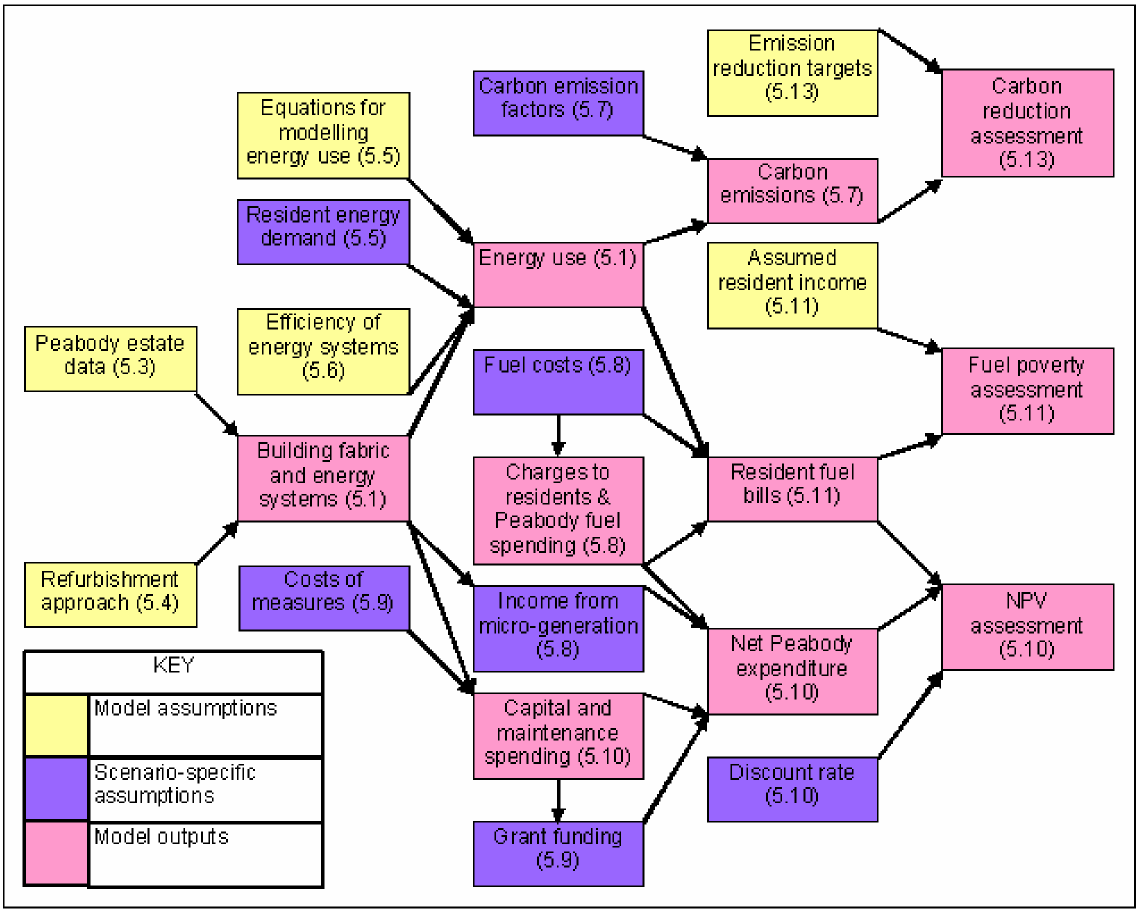

Figure 5.1 The Peabody Energy Model

5.1 Modelling energy use

To meet the aims of this research, a model was required that could generate each of the required outputs shown in Figure 5.1, which was compatible with the data available for Peabody estates, and which allowed the values of model inputs to be changed so that sensitivity analysis could be carried out. The potential use of two existing software tools was considered, including the Fuel Prophet tool (ACE and EAGA 2009), and National Home Energy Rating (NHER) software used by Peabody to estimate stock carbon emissions. No existing software identified could meet the criteria for this research, so a new computer model was created specifically for Peabody stock.

Model-based research on energy use in UK housing has most commonly taken a "building physics" approach, estimating energy use by combining assumptions on dwelling properties, energy systems and energy demand with equations based upon a physical analysis of energy flows within a dwelling (Shipworth 2008). Each of the studies discussed in section 2.4 took this approach, where the models used were based upon BRE's Domestic Energy Model (BREDEM) (BRE 2001), which is a "de facto industry standard" in the UK (RICS 2006).

The "building physics" approach has been compared to a method using Bayesian Belief Networks (BBN) by Shipworth (2008). Two key differences that distinguish a BBN approach from a building physics approach are that probabilistic relationships, rather than fixed relationships, are specified between model variables, and that probability density functions are used to specify the values of model variables across a whole population, rather than using "archetypes" or average values to represent a whole population (ibid). Such an approach could be highly beneficial for a study of domestic energy use, where variables such as energy demand and income levels vary significantly across a population and factors affecting energy demand (such as income or dwelling size) are inter-dependent, making energy demand challenging to describe through simple equations (as discussed in 2.2). A BBN approach could however greatly increase the model's complexity and would not be possible to implement using software packages (such as spreadsheets) which require fixed values for variables and fixed relationships between them.

For this research, a physical-based model based upon BREDEM was chosen and implemented using spreadsheet software. The benefits of this approach relative to a BBN approach were: relatively straightforward implementation using the existing skills of the researcher; well-established equations for estimating variables and their relationships could be used; compatibility with previous research that the present research builds upon, such as Dwyer (forthcoming) and Boardman et al. (2005a).

Where a population is modelled using a building physics approach, a key question to be addressed is the level of disaggregation, namely the extent to which the considered housing stock is broken up into smaller units for the purposes of analysis. A number of contrasting approaches to this can be found in research on existing UK housing, such as the use of two archetypes by Johnston et al. (2005), 73 variants in the TARBASE project (Peacock et al. 2007), or the thousands of dwelling types modelled by Boardman et al. (2005a). Increased disaggregation is likely to provide more accurate results (Shanks et al. 2006), whilst also being more demanding to model in terms of resources and required data. The decision taken on disaggregation therefore took into account the resources available to the researcher, the nature of model outputs required and the level of accuracy needed. The method of modelling energy use on an estate-by-estate basis was chosen, as this involved a manageable depth of analysis, fits with the availability of data (which is typically at an estate-level) and would provide results at a useful level of detail for Peabody. Given the relatively broad level of the technical analysis, it is intended to identify key issues to inform the wider analysis in this thesis, rather than a highly detailed assessment of Peabody stock.

Due to the focus in this research on emissions that can be attributed to Peabody estates as and when energy use takes place, the model did not take the embodied carbon emissions of refurbishment options into account. Embodied emissions are those associated with the full life-cycle of a measure, incorporating the extraction and processing of raw materials, manufacture, installation, use, and eventual disposal of each refurbishment measure. This omission is a limitation of the current study, as it means that the full impacts on climate change of the options modelled are not evaluated. Due to the lack of comprehensive data on embodied emissions of each of the measures studied, their consideration could not be satisfactorily achieved in practice even if a decision to model them had been taken.

5.2 Scenarios

A number of future socio-economic issues, such as Government policy, economic conditions and social values, will have a significant influence on the carbon emission reductions that can be achieved in Peabody stock. As future conditions are uncertain, scenarios have been used to specify a range of possible futures in which the considered approaches to refurbishment are carried out. This section describes the key issues used to define scenarios, and discusses the four scenarios used in this study.

5.2.1 Relevant issues

Existing research on future trends in energy use in housing and UK carbon emissions has identified a number of key issues affecting domestic emissions. These include: levels of domestic energy demand; availability of heat and electricity from renewable sources; take-up of energy saving technologies; technological innovation; economic growth; fuel costs (IPCC 2000; BRE 2005; Johnston et al. 2005; Tyndall Centre 2005; Boardman et al. 2005a; ACE 2005b). Scenarios-based research focussing on broader social trends has identified a number of key issues around which future decades could be defined: levels of social cohesion, openness of economies; dominant values (social or individualistic); scale of economies (globalisation or localisation) (Carnegie Trust 2007; Skea and Nishioka 2008; Young Foundation 2008).

Scenarios are best defined around issues that are both highly significant for research outcomes, relatively independent of each other, and for which there is a high degree of uncertainty attached (Schwartz 2001). For this research, scenarios were defined by the researcher through consideration of both the key themes identified in the literature above and consideration of the model variables that would be influenced by differing scenarios. Two issues were then chosen to define scenarios that are able to capture many of the issues listed above: trends in fuel price levels (5.2.2) and the extent of action taken in the UK to mitigate climate change (5.2.3). Although not wholly independent of each other (as, for example, strong efforts to mitigate climate change could lead to higher fuel costs), these factors were judged to be the most useful for defining contrasting possible futures based upon the criteria stated above.

5.2.2 Fuel price levels

The future prices for domestic fuels used on Peabody estates (gas, electricity and potentially biomass) will determine fuel bills for Peabody residents, and as a result, the extent of fuel poverty. In addition, they affect the financial case for investments: for example, high electricity prices relative to gas prices improves the financial case for CHP. Fuel price levels can also be expected to be associated with a number of the scenario issues introduced above. Very high fuel prices are likely to lead to reduced demand for energy. Politically, they are likely to lead to a greater focus on providing affordable warmth in housing, potentially leading to increased financial support for insulation measures.

Domestic fuel price levels have been historically correlated with the price of oil, and this trend is likely to continue for the foreseeable future (Powry Energy 2007). Oil prices have fluctuated significantly over recent years, rising sharply until mid-2008, and then declining rapidly as the recent global economic downturn led to a reduction in demand. The context over coming years appears likely to be one of supply struggling to match demand (IEA 2008), leading to the conclusion expressed by both Government and energy industry officials that “the era of cheap oil is over” (Golby 2008; Porter 2008). As a result, it was assumed for every scenario that the overall trend in fuel prices to 2030 is upwards in real terms.

There is however disagreement and considerable uncertainty on the likely nature of fuel price changes over coming decades and the knock-on impacts on the global economy. Some analysts have pointed to the current dependence of the global economy on energy from oil (Greene et al. 2006), and a likelihood of declining supplies over coming decades (Campbell and Laherrere 1998; Hallock et al. 2004) leading to a long-term contraction of the global economy (Hirsch et al. 2005; Feasta 2007). The more conventional view is exemplified by the stance taken by the UK Government, which has stated that “global oil (and gas) reserves are sufficient to sustain economic growth for the foreseeable future” (Monbiot 2008), where “the foreseeable future” refers to the period cited in research by the International Energy Agency (IEA 2005), namely from the present day to 2030.

Scenarios are therefore defined around these two contrasting futures, with relatively low fuel price increases and continued economic growth informing one pair of scenarios, and high fuel prices and stalled economic growth defining the second pair of scenarios.

5.2.3 Climate change mitigation

The level of action taken in the UK, both by Government and wider society, to mitigate climate change (by reducing carbon dioxide emissions) affects a number of key issues impacting on energy use in Peabody homes. Substantial investment in renewable energy for the national grid, or decentralised generation within London, would provide sources of low-carbon energy for Peabody homes. Measures to bring about changes in energy use behaviour, such as bringing in a system of Tradable Energy Quotas (Fleming 2007), or improved feedback for householders on energy use (Darby 2006), could significantly reduce demand for energy in Peabody homes, and in the UK as a whole.

There is some uncertainty about the future extent of UK efforts to reduce carbon emissions. The UK Government has recently committed to a statutory carbon reduction goal of 80% reductions by 2050 (DECC 2008), which will potentially trigger strong action. However, with energy security also being a goal of UK energy policy, there is potential for carbon-intensive energy sources such as coal-fired power stations to be increasingly used in future years. The uncertainty around UK efforts to mitigate climate change was therefore also used to distinguish scenarios. Two scenarios were defined around strong efforts to mitigate climate change, and two scenarios were defined around relatively weak action.

5.2.4 Four scenarios

Four scenarios were specified based upon the two defining features described above to provide a frame in which future socio-economic trends affecting research outcomes can be understood (Table 5.1). The defining qualities of each scenario and the "back-story" in terms of broader societal changes are illustrated in Figure 5.2, where the position of each scenario is intended to represent visually where it fits into the range of future possibilities as defined by the two axes. The scenarios are positioned close to the centre of the graph, as they are intended to represent relatively moderate changes, rather than more extreme visions of the future. For example, the strong action on climate change advocated in the report Zero Carbon Britain (CAT 2007) would be more radical than the action assumed for the Power Down scenario. Many of the future scenarios reviewed by Hopkins (2006) that point towards sustained high fuel prices triggering economic and social breakdown are much more extreme than the Breaking Down scenario considered in this research.

Keeping the Lights On (KLO) *Low fuel prices, weak action on climate change.*	Concerns about energy security over-ride action on climate change. Assumed: continued economic growth, a continuation of present-day trends in domestic energy demand, and a relatively low increase in grid electricity provided by renewables.
Sustainable Development (SD) *Low fuel prices, strong action on climate change.*	Strong measures to mitigate climate change in the context of a growing economy. Assumed: substantial grant funding for refurbishment, significant increases in renewables supplying the grid and reduced domestic energy demand.
Breaking Down (BD) *High fuel prices, weak action on climate change.*	Strong focus on energy security but with very high fuel prices leading to a series of deep recessions. Assumed: marginal reduction in domestic energy demand due to high prices, low use of grid renewables and low Government support for domestic energy saving measures.
Power Down (PD) *High fuel prices, strong action on climate change.*	Strong efforts to reduce carbon emissions with a focus on reducing energy demand, which partially mitigates the impact of high fuel prices on fuel bills and the economy. Assumed: strong financial support for refurbishment and increases in renewables supplying the grid.

Table 5.1 The four scenarios

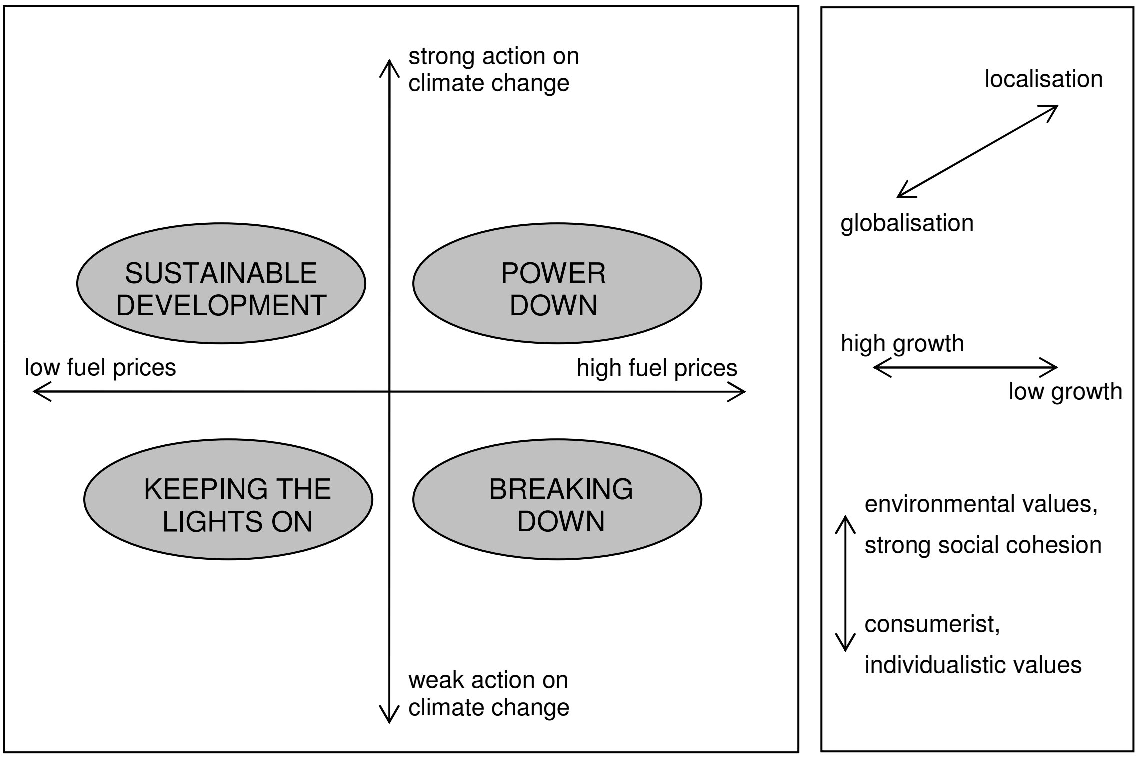

Figure 5.2 The four scenarios and their defining features

The scenario definitions were then translated into assumptions affecting model outputs. The key assumptions are illustrated in Table 5.2 below and listed in full in Appendix H. The rationale behind each assumption is given in the relevant section of this chapter.

Issue	Scenario Assumptions
Carbon intensity of grid electricity	Declines more rapidly in PD and SD scenarios than KLO and BD. By 2025, falls by 29% relative to 2006 levels for KLO/BD, and by 51% for SD/PD. By 2030, reductions are 39% and 68% respectively.
Demand for energy services	KLO continues current trends, with electricity demand increasing and other uses stabilising. Environmental concerns lead to reductions for SD and PD. High fuel prices lead to reductions for PD and BD. Changes to 2030 for electricity: +48% (KLO); -7% (SD); -20% (PD); +2% (BD). Changes to 2030 for other energy use: +0% (KLO); -11% (SD); -23% (PD); -13% (BD).
Grant funding	Greater support in PD and SD scenarios. A fraction of estates in “Low Carbon Zones” receive refurbishment at no cost to Peabody (21% of estates in SD, 30% in PD). On other estates there is grant funding for insulation (5% of costs for KLO, 20% for SD, 30% for PD, 10% for BD) and renewables (5% for KLO and BD, 30% for SD and 20% for PD).
Support for micro-generation	Renewable heat obligation brought in for PD and SD. Feed-in tariffs brought in to support electricity generation in SD.
Discount rate	Relates to assumed economic growth rate. The Treasury recommended rate of 3.5% is assumed for KLO and SD. Lower assumed growth rates lead to assumptions of 2% for PD and 1.5% for BD.
Fuel prices	Increases are greater in PD and BD. PD and SD scenarios have relatively higher increases for electricity due to strong investment in renewables. Gas prices in 2030 relative to 2008 levels are greater by 24% (KLO), 39% (SD), 72% (PD), 113% (BD). Electricity prices are greater by 24% (KLO), 72% (SD), 113% (PD), 92% (BD).

Table 5.2 Scenario assumptions

5.3 Peabody estate data

This section introduces the Peabody estates modelled (5.3.1) and describes the estate data either obtained from Peabody (5.3.2) or derived from other sources where this was not possible (5.3.3).

5.3.1 Estates modelled and classifications used

In total, 189 of Peabody's 195 existing estates were modelled, consisting of 16,901 dwellings in the base year 2006. Estates were excluded from the analysis either because: Peabody has no maintenance responsibilities towards them; they were being sold by Peabody; or if recommendations for refurbishment would have little practical value due to the very high standards already in place. Leaseholder dwellings on estates were also excluded from the model analysis. This is because leaseholders are responsible for any internal improvements to homes, and would be expected to pay a proportionate contribution towards any external estate improvements.

Estates were grouped together within the model according to their current and potential future energy servicing regimes (Table 5.3). For all estates equipped with individual gas boilers, each estate's boiler installations were classified as either New (meaning that all homes are fitted with modern combination boilers) or Old (meaning that the estate contains a mixture of modern boilers, old boilers, room heaters and a small percentage of homes with electric storage heaters). These classifications were used to determine the average boiler efficiencies on each estate, using data from Peabody on the proportions of each boiler type installed, and boiler efficiency data (given in section 5.6).

Individual Gas Boilers	125 estates, comprising 6,487 units, where individual gas boilers are the dominant heating system
Part Gas, Part Electric	3 estates, comprising 126 units, heated by either gas boilers or electric storage heaters
All Electric	13 estates, comprising 332 units, where all energy is currently supplied by electricity
Communal	16 estates, comprising 2,815 units, where some or all of the units are heated by communal systems. Typically, the existing communal systems supply heat to sheltered housing blocks
Communal Potential	32 estates, comprising 7,141 units, each having the potential for estate-wide communal heating to be installed (defined in 5.4.4)

Table 5.3 Groupings of Peabody estates

5.3.2 Data obtained from Peabody

Data on each estate were collected from Peabody's staff, internal documents and databases. Items used for the model are shown in Table 5.4, along with the source of the data and a comment based upon the researcher's judgement on the quality of the data in question (good, adequate or poor).

Data item	Source	Quality of data
Year of construction	Planned maintenance spreadsheet	Good
Number of units	Planned maintenance spreadsheet	Good
Number of leaseholder dwellings	Planned maintenance spreadsheet	Good
Built form (blocks/terraces/scattered houses	Property portfolio estate descriptions	Good
Energy supply systems	Property portfolio estate descriptions	Adequate
Average number of residents per unit	Property database	Poor
Average number of bedrooms per unit	Property database or property portfolio	Adequate
Year of Decent Homes work	Planned maintenance spreadsheet	Good
Listed/conservation area status	Planned maintenance spreadsheet	Good
Inclusion in disposals strategy	Planned maintenance spreadsheet	Good
Glazing type installed (double/single)	Planned maintenance spreadsheet	Good
Wall insulation	Based on year of construction	Poor
Number of houses/bungalows	Planned maintenance spreadsheet	Good
Fraction of houses/bungalows with gardens	Property portfolio estate descriptions	Adequate
Fraction of dwellings with flat roofs	Planned maintenance spreadsheet	Good
Number of homes currently supplied by communal heating system	Communal heating asset register	Good
Number of units with gas cookers	Gas team database	Good
Number of storeys	Property portfolio estate descriptions	Adequate
Roof area suitable for PV	Consultancy report on available PV roof-space	Adequate

Table 5.4 Peabody data used in model

Two data items appeared to be of relatively poor quality. The first was the data on the number of residents in each home, which was derived from original tenancy agreements and typically not updated. These figures could either be over-estimates if some members of a household have moved out or died, or under-estimates if householders have had children or are subletting. Assuming that these effects will to some extent cancel each other out and given that large changes in average occupancy levels are unlikely where the number of available bedrooms remains unchanged, these figures can be assumed to be of reasonable accuracy. The second item was whether estates had solid walls, and whether these walls had been insulated. It was assumed that pre-war estates had un-insulated solid walls, which Peabody staff identified as a reasonably accurate assumption.

Other data items which are listed as being "adequate" above typically had data missing for a minority of estates. In these cases it was assumed that the item in question was equal to the average figure for the remainder of the stock.

5.3.3 Other data

For several important model variables, comprehensive data were not available from Peabody, so assumptions were based upon existing research, as described below.

5.3.3.1 Average floor area per dwelling

Data on average floor areas were only available for 12 of the 189 Peabody estates modelled. To generate a value for the remaining estates, data from the English House Condition Survey (EHCS) (CLG 2008b) were used. The EHCS data matches average floor areas with number of bedrooms for surveyed English dwellings. A curve of best fit was generated for this data using the statistical package SPSS, to generate the following equation expressing floor area as a function of number of bedrooms:

$$\text{Floor Area} = 29.516 \times e \wedge (0.366 \times \text{Number of Bedrooms})$$

It was expected that this function would over-estimate floor areas for Peabody stock, as the greater than average competition for land in the London area relative to the English average would be likely to lead to dwelling sizes being smaller than average. Checking the function against figures for the Peabody estates where floor area data was available supported this hypothesis, with the discrepancy being larger for the larger estates. To correct for this discrepancy, a constant K was introduced into the above equation, giving:

$$\text{Floor Area} = 29.516 \times e \wedge (K \times 0.366 \times \text{Number of Bedrooms})$$

A value for K was calculated using data from the English House Condition Survey regional report (CLG 2006), which contrasts floor areas in London and the rest of England, to generate a curve using SPSS with a value for K of 0.92. When compared to the data points where average floor areas were known (Figure 5.3), this curve appears to provide a reasonable estimate.

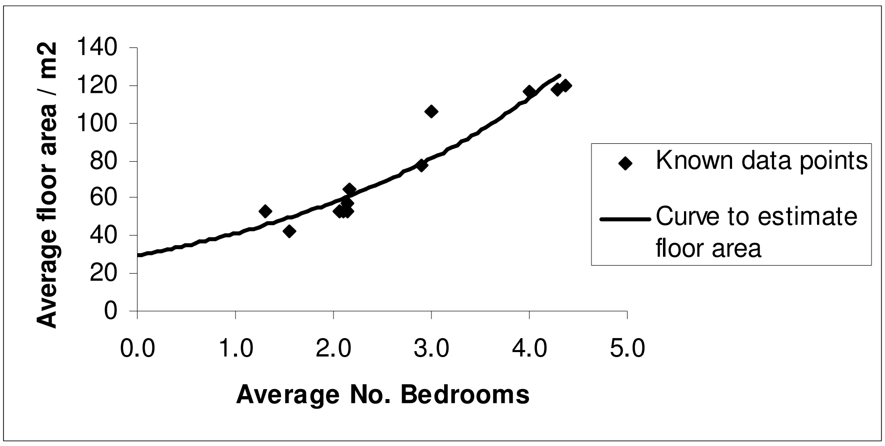

Figure 5.3 Estimation of average floor areas

5.3.3.2 Average window area per unit

Average window areas were estimated using equations from SAP 2005 (BRE 2006c), which give figures based upon year of construction, total floor area (TFA) and type of dwelling (Table 5.5). For each estate an average was calculated for flats and any houses on the estate, and these figures were used to create an overall average. For estates with a varied age profile, the figures for 1950-1966 (a period roughly midway in the range of dates when Peabody estates were built) were used.

Age Band	House or Bungalow: Window Area (WA) in square metres	Flat or Maisonette: Window Area (WA) in square metres
Before 1950	WA = 0.1220 TFA + 6.875	WA = 0.0801 TFA + 5.580
1950-1966	WA = 0.1294 TFA + 5.515	WA = 0.0341 TFA + 8.562
1967-1975	WA = 0.1239 TFA + 7.332	WA = 0.0717 TFA + 6.560
1976-1982	WA = 0.1252 TFA + 5.520	WA = 0.1199 TFA + 1.975
1983-1990	WA = 0.1356 TFA + 5.242	WA = 0.0510 TFA + 4.554
1991-1995	WA = 0.0948 TFA + 6.534	WA = 0.0813 TFA + 3.744
1996-2002	WA = 0.1382 TFA – 0.027	WA = 0.1148 TFA + 0.392
2003 onwards	WA = 0.1435 TFA – 0.403	WA = 0.1747 TFA – 2.834

Table 5.5 Equations for average window areas

5.3.3.3 External wall area per unit

The method used follows that used by Boardman et al (2005b), with wall area for a dwelling given as:

Total wall area = perimeter × storey height (2.5m) × number of storeys per dwelling

Dwellings are assumed for simplicity to be square, making the perimeter 4 × √ (floor area / number of storeys). This assumption provides a minimal estimate of circumference (and therefore the area treatable by solid wall insulation) for a given floor area, and as a result a relatively conservative estimate of insulation costs. The number of storeys per dwelling is estimated based upon the average total floor area (TFA) for the estate. It is assumed that dwellings have one storey if TFA < 70, two storeys if 70 ≤ TFA < 100, and three storeys if TFA ≥ 100, based upon the number of storeys in dwellings on Peabody estates where floor areas are known.

The total exposed external wall area (including windows and doors) is calculated from the above estimate using the approach taken by Boardman et al (2005b): multiplying by a correction factor of 0.4 for flats and mid-terrace houses and 0.7 for end-terrace houses. It is assumed for simplicity that all Peabody houses are terraces, as only a small fraction are either detached or semi-detached. It is assumed that 75% are mid-terraces and 25% are end-terraces, based upon average terrace lengths of around eight units indicated by estate descriptions in Peabody's property portfolio. This gives an average correction factor for houses of 0.475.

External exposed wall area (excluding windows and doors) is then the total exposed external wall area subtracted by window area (generated using SAP 2005 equations, described above) and door area (1.85m^2 per door, assuming one door for flats, two doors for houses (BRE 2006c). This is the area assumed to be treated with solid wall insulation when that intervention is carried out.

5.4 Refurbishment approaches

It is assumed that Peabody's refurbishment programmes for meeting the Decent Homes standard continue to 2010. This assumption takes into account that these programmes, which have already been planned, budgeted for, and procured, are very unlikely to be changed up to that date. Decent Homes refurbishment is assumed to be followed by one of four possible refurbishment approaches (Base, Fabric, Communal, Renewables) from 2011 to 2030, summarised in Table 5.6.

Base	After Decent Homes improvements are complete in 2010, the only improvements to the fabric of Peabody Homes that impact upon energy use are double-glazing installations, carried out when windows need to be replaced. No changes are made to building services, except for existing heating systems being replaced by new models when due for replacement.
Fabric	Improvements to building fabric and some building services are carried out after 2010 on each estate. Measures are applied in a single visit to each estate as required from a package consisting of: external solid wall insulation; double-glazing; extractor fans; thermostatic radiator valves; heat meters and improved controls (for communally heated homes); replacement of storage heaters with gas boilers. Homes that cannot be externally insulated are insulated internally as they are vacated by residents from 2011 to 2030.
Communal	As for the Fabric approach, but estates are connected to district heating networks where a connection is available. Communal heating supplied by CHP is installed on other estates where feasible.
Renewables	As for the Communal approach, but solar PV panels and solar thermal panels are installed on all available suitable roof space.

Table 5.6 Summary of refurbishment approaches

Each refurbishment strategy extends the work carried out in previous approaches, making analysis of the model results relatively straightforward. The order of application of interventions that go beyond the Base approach (Fabric, then Communal then Renewables) reflects a preference to carry out the most cost-effective measures first and a preference to first reduce energy demand, then improve energy efficiency and finally to generate energy. Each refurbishment approach considered is described in more detail below.

5.4.1 Decent Homes

Any estates with Old (as defined in 5.3) heating services have gas central heating installed to replace room heaters. Electric storage heaters on these estates remain installed, as is current Peabody practice. This leads to an assumed 5% of homes on estates with Old heating services retaining electric storage heaters after Decent Homes work is complete.

Peabody's experience to date is of a small minority of residents refusing central heating installations, creating the need to install central heating at the end of their tenancy. The PEM uses the simplifying assumption that no refusals take place, and that all gas room heaters are replaced with gas central heating by the Decent Homes programme. Estates with existing communal heating receive thermostatic radiator valves (TRVs) as a result of the Decent Homes improvements, improving the assumed efficiency of the communal boilers.

Peabody's Decent Homes work is being funded in part through disposals of dwellings on a selection of its estates. Based upon Peabody data it was assumed that a further 600 homes are sold from 2006 to 2011, with an approximately equal proportion of homes sold on each of the estates affected.

5.4.2 Base

After the Decent Homes programme is complete in 2010, no further changes are made to the types of energy supply systems installed on Peabody estates. Gas boilers, electric storage heaters and communal boilers are replaced on a like-for-like basis to 2030. This brings about an improvement in efficiency as older boilers are gradually replaced by more-efficient modern boilers.

Peabody estimates that almost all estates will be double-glazed by 2050 under current projected plans and budgets, so it was assumed that half of the estates requiring double-glazing after the Decent Homes programme is complete will receive it by 2030. The work was assumed to be carried out in the year allocated to the estate for fabric improvements, described below.

5.4.3 Fabric

A package of measures to improve the building fabric and some services is applied to each estate through a one-off visit after 2010. The selection of measures and U-values achieved by insulation are based upon the enhanced Fabric package considered by Dwyer (forthcoming). Measures are applied where required from those given in Table 5.7.

Solid wall insulation	Applied externally on any estates with uninsulated solid walls, except for listed estates or estates in conservation areas, to achieve a U-value of 0.38 W/m^{2}K.
Double-glazing	Wooden-framed units installed giving a U-value of 1.6 W/m^{2}K.
Extractor fans	Low energy-use extractor fans installed in the kitchen and bathroom where required (for 80% of dwellings on estates with Old gas heating systems).
Thermostatic radiator valves (TRVs)	Five TRVs installed per unit where required (for 75% of dwellings on estates with Old gas heating systems).
Replacement of storage heaters with gas boilers	Condensing gas combination boilers installed in place of electric storage heaters wherever present. Estates treated are current all-electric estates, part-electric estates and estates with Old heating installations.
Heat meters and improved controls	Individual heating controls installed on estates with existing communal heating so that residents can be billed according to use (providing an assumed improvement in system efficiency as less heat is wasted).

Table 5.7 Description of fabric measures

The exception to this single-visit approach is for listed estates or estates in conservation areas. In addition to the single visit detailed above, it is assumed that from 2011 to 2030 internal wall insulation, extractor fans and floor insulation (for ground floor units) are installed in void dwellings as they become available. Internal wall insulation is assumed to achieve the same U-value as external wall insulation of 0.38 W/m^{2}K (Dwyer 2007). Floor insulation is assumed to achieve a U-value of 0.22 W/m^{2}K (ibid). With a stock turnover rate of 4% (based on Peabody data), 54% of homes on such estates would be treated by this approach by 2030.

In all scenarios, estates are visited for single-visit improvements over the period 2011 to 2024, so that the benefits of refurbishment have been realised by 2025, the year when progress is assessed against the GLA target. The order of works planned in Peabody's existing cyclical refurbishment programme specifies the order of visits to estates, and an equal number of estates are assumed to be treated each year.

For the SD and PD scenarios, a fraction of estates are assumed to receive refurbishment at no cost in the period 2011 to 2015. This is based upon the idea of "Low Carbon Zones" put forward by Boardman (2007), as a funding and delivery mechanism to combat fuel poverty and reduce carbon emissions in existing housing[1]. This one-off refurbishment covers the costs of all fabric measures, district heating connections, heat pumps and solar thermal installations. At the time of writing, the UK Government is currently looking to trial a funding approach close to this through its Community Energy Saving Programme (CESP) (DECC 2009b).

5.4.4 Communal

This approach includes the measures described for the Fabric approach above, and adds the installation of communal heating systems on suitable estates. Communal interventions take place at the same time as fabric measures, except for estates receiving CHP installations that fall in Low Carbon Zones: in this case the year of fabric works is moved forward, taking place by 2016, whilst the CHP installation date remains unchanged.

Technical constraints such as lack of space for a CHP plant room or for pipework to deliver hot water are likely to make it impractical to install communal heating on a number of Peabody estates (RTA 2003), although the particular estates to which these constraints would apply is unknown. As a result, it is assumed that only 80% of Peabody estates are suitable for communal heating, with the 20% of estates that are unsuitable chosen at random.

CHP was considered as an intervention for estates with existing communal heating, and for “Communal Potential” estates (5.3). Estates were put in the Communal Potential group if they were built in blocks and had a minimum of 100 dwellings. This decision reflects experience that communal heating is more likely to be financially viable for higher density estates, where expenditure on heat distribution pipework is minimised, and for larger estates, as installation and maintenance costs per dwelling typically decrease as the number of dwellings increases (RTA 2003; Action Energy 2004). A review of energy efficiency at Peabody in 2007 estimated the minimum number of units required for CHP to be financially viable at 100–200 (Peabody Trust 2007a).

Based upon these figures, the lower limit of 100 estates was used as a minimum number of units for estate-wide CHP to be considered. This assumption is not intended to imply that systems serving less than 100 homes could not be a viable technical option, as it is possible that mini-CHP, supplying small clusters of homes, could have a role to play. The

[1] A distinct proposal to the “Low Carbon Zones” currently being developed by the GLA

aim of the assumption was to allow the exploration of the impacts of installing CHP systems on larger, high-density Peabody estates, as this intervention has been recommended to Peabody in previous research (RTA 2003).

As CHP is best-suited to dense areas of housing where spending on pipework can be minimised, any stand-alone houses on estates considered for CHP were not assumed to be connected. In contrast, where district heating is modelled, it is assumed that a connection is available through a local heat network for all dwellings on estates with an available connection.

District heating is assumed to be certainly available for six Peabody estates where existing networks already exist, and for further estates (selected at random) depending upon scenario assumptions. It is assumed that medium to large scale CHP systems are used to provide district heating (as is the case for a Peabody estate that has most recently connected to a district heating network), so heat from such networks has a relatively low overall carbon emission factor because of the electricity that is also generated (see Table 5.13). Only estates in central London boroughs are considered, based on research that identified these areas as the most suitable for district heating in London (Greenpeace 2006). For the SD and PD scenarios, 25% of estates have this option (based upon the GLA aspiration of 25% of London's energy coming from decentralised energy by 2025 (GLA 2007)). For the KLO and BD scenarios, only 10% of estates are assumed to have a potential connection. Each of these assumptions reflects a significant increase in district heating availability in London, a position taken due to the strong focus being placed by the GLA on developing this infrastructure over coming years (ibid).

For Communal and Communal Potential estates, gas-fired CHP systems are installed if no district heating connection is available. For these estates, the CHP is sized to meet the base hot water demand for the estate throughout the year, a decision based upon Peabody experience of sizing CHP systems on well-insulated estates. This was done because of the assumption that heat loads would either be low, due to insulation improvements, or gradually reducing to a low level (on estates where void dwellings are insulated as they become available). Based upon guidance for CHP sizing and running times (CIBSE 1999; Hinojosa et al. 2005), it is assumed that the CHP systems provide hot water year-round, running for 6200 hours a year.

5.4.5 Renewables

This approach builds upon the Communal approach, with the following additions: solar thermal panels are installed to supply hot water to top floor flats and houses; solar PV is installed on all remaining appropriately-oriented roof space.

5.4.5.1 Solar PV and solar thermal

To avoid competition between servicing options, it is assumed that solar thermal panels are not installed alongside communal heating. Neither solar thermal nor solar PV is installed on estates that are listed or in conservation areas. It is assumed that $4m^2$ of solar thermal panels are installed for each house and, following the approach taken by Dwyer (forthcoming), for top floor flats where south-facing roof space is available. Solar PV is assumed to be installed on all remaining available roof space (except on north facing roofs), a decision taken to identify the full extent of reductions achievable through its use.

Installations are limited by the availability of suitable roof space. It is assumed that total roof space for an estate is equal to the total footprint of the estate's buildings. This is calculated as:

$$\text{Total roof space} = \frac{\text{number of dwellings} \times \text{average dwelling floor area}}{\text{average number of storeys on estate}}$$

For many Peabody estates, data was available for total roof space broken down by orientation (flat, south-facing, east-facing, west-facing or north-facing) from research carried out by consultants into the potential for solar PV on Peabody estates (Whitby Bird & Partners 2001). Where available, this data was used, except in a minority of cases where it was rejected in favour of an estimate using the above equation, due to the value provided being more than 2/3 of the value of the estimated roof space, indicating a likely error. For estates with pitched roofs where roof areas were estimated, 25% of total roof space is assumed to be oriented south / north / east / west. 70% of the area of all pitched roofs is assumed to be free of obstructions and shading so as to be suitable for solar panel installation (Whitby Bird & Partners 2001). For flat roofs, 50% of their area is assumed to be suitable (ibid).

5.4.5.2 Heat pumps

Ground source and air source heat pumps are not considered as part of the original Renewables approach, but their potential impacts are reported in chapter 7. It is assumed that both technologies are installed in combination with over-size radiators, due to the disruption and extra costs involved in installing underfloor heating (which would be a more efficient option) in existing dwellings (Housing Corporation 2008a).

GSHPs are considered for all houses with gardens on Peabody estates, with a borehole being used to house the heat pump pipework. This assumption is likely to represent an upper limit on their applicability, as many sites will either not be suitable for a borehole, due to underground services or unfavourable ground conditions, or be inaccessible for a drilling rig (Housing Corporation 2008a). ASHPs are installed in flats on estates that are not listed or in conservation areas (due to the visual impact of the units) and where average floor areas are below $60m^2$ (WWF 2008).

To avoid competition with communal infrastructure, heat pumps are not installed on estates receiving a district heating connection. As they provide both space heating and hot water, they are used in preference to solar thermal where that option is also available.

5.4.5.3 Communal biomass boilers

Communal biomass boilers fuelled by woodchip are also considered as an alternative to gas-fired CHP in chapter 7. The same approach to sizing and running hours is employed as for gas-fired CHP. They are also assumed to be used in combination with gas-fired backup boilers, following the approach taken by Dwyer (2007) based upon recent common practice (CIBSE 1999).

5.5 Estate energy demand

Demand for energy refers to the end-use energy providing an energy service (such as thermal comfort or hot water) to residents. It is therefore distinct from the total energy supplied to Peabody dwellings, which will be greater where losses due to inefficiency take place. For simplicity, this demand is assumed to be independent of the energy systems installed. The impacts on energy use that can result from a change in installed technologies (such as shifting patterns in electricity use that can take place when solar PV is installed (Kirwan 2008; Bergman 2009)) are therefore not considered.

The PEM takes BREDEM as a starting point (BRE 2001), which estimates domestic energy demand as a function of floor area and number of residents. Following the BREDEM approach, the modelling of energy demand and equations for base demand levels are described in this section using five distinct categories: heat (5.5.1), hot water (5.5.2), lighting (5.5.3), cooking (5.5.4) and (other) electricity (5.5.5). Changes in assumed demand levels beyond the base year are then described in section 5.5.6.

5.5.1 Heating

Demand for energy for heating is assumed to depend upon the built form of the estate and an estimate of heat demand per unit area for each type of dwelling considered. The model assumes that for a given dwelling type, heat demand increases linearly with floor area, an assumption supported by studies using monitored data (Hong et al. 2006; Baker 2007). Flats and houses were considered separately, so on estates containing both dwelling types, an average heat demand figure based upon their relative proportions was calculated. The option of basing heat demand estimates on average SAP data for estates was actively explored, but not pursued due to inadequate availability of Peabody data.

Although heat demand levels are commonly estimated by researchers based upon the physical properties of dwellings, studies using monitored energy use have identified a weak correlation between built form and energy demand (Wright 2008). Where the influence of energy efficiency of UK dwellings, as measured by SAP ratings, has been explored, little or no correlation has been found with energy used for space heating (Hong et al. 2006; Summerfield et al. 2006; Baker 2007; Hinnells et al. 2007). However, the above studies were carried out on homes within the typical SAP range for the existing UK homes — monitoring of highly insulated homes with very high SAP ratings, such as Peabody's BedZED development, have shown that energy demand for space heating is considerably lower than average (Bioregional 2004).

Based upon these findings, this research does not distinguish between dwellings with very similar built form, and instead estimates heat demand on the basis of whether or not they have a number of key measures to reduce heat losses installed: loft insulation and draught-proofing (carried out through Decent Homes), solid wall insulation, double glazing and floor insulation.

The assumptions for heat demand per square metre are derived from the Community Domestic Energy Model (CDEM), an implementation of the BREDEM model applied to different dwelling types developed at De Montfort University and successfully validated against regional energy consumption data (Firth 2007). Model outputs were available from the CDEM for "average" flats and detached houses, based upon assumptions of the physical properties of typical blocks of flats or streets of houses. As Peabody houses are typically terraces and are rarely detached or semi-detached, values for Peabody houses were estimated by using a figure mid-way between those available for flats and detached houses. The values used are shown in Tables 5.8 and 5.9.

	Base estimate (kWh/m2)	Insulated wall reduction (kWh/m2)	Double glazing reduction (with no wall insulation) (kWh/m2)	Floor insulation reduction (kWh/m2)
Pre Decent Homes	141.1	59.7	25.3 (23.1)	
Post Decent Homes	123.2	54.8	23.2 (21.2)	5.1
Modern (post 1991)	45.5			

Table 5.8 Heat demand per unit area for flats

	Base estimate (kWh/m2)	Insulated wall reduction (kWh/m2)	Double glazing reduction (with no wall insulation) (kWh/m2)	Floor insulation reduction for ground floor units (kWh/m2)
Pre Decent Homes	163.5	66.9	25.2 (24.8)	
Post Decent Homes	146.1	62.8	23.6 (23.3)	6.0
Modern (post 1991)	57.3			

Table 5.9 Heat demand per unit area for houses

Due to evidence that physical-based domestic energy models often over-estimate the extent of heat demand savings due to insulation improvements (Milne and Boardman 2000; Hong et al. 2006; Sanders and Phillipson 2006; Ouyang et al. 2009), it was assumed that not all of the benefits suggested by the original CDEM figures were realised. This was done by calculating the reduction in heat demand for each dwelling type relative to the most energy inefficient dwelling of the same built form (pre-Decent Homes, single glazed with uninsulated solid walls), and assuming that only 85% of this reduction was realised. The 85% figure is based upon the estimate put forward by Milne and Boardman (2000) and Sanders and Phillipson (2006) of 15% of the benefit of insulation improvements being “taken back” by householders through increased temperatures. This is a relatively conservative assumption, as research has identified up to 50% of expected demand reduction not being realised when all factors are considered (Sanders and Phillipson 2006). The impact of changing the assumed effectiveness of fabric improvements was therefore explored through a sensitivity analysis.

It is assumed that the level of heat demanded by Peabody residents in the base year 2006 is equal to the level given by the CDEM.[1] This judgement is based upon evidence from the survey of Peabody residents conducted at the residents’ conference in 2007 (see Appendix

[1] Note that the figures taken from the CDEM are based on BREDEM equations and do not incorporate climate data from 2006.

E), which indicated that the hours of assumed heating use in BREDEM are a reasonable approximation of Peabody residents' heating use.

5.5.2 Hot water

Hot water demand is assumed to be a function of the number of residents in a dwelling. In BREDEM, daily hot water demand (Q_u) for an average dwelling, measured in GJ, is modelled by the equation:

$$Q_u = 8.64 \times 10^{-5} \times (78 + 52 N)$$

where N is the number of occupants (BRE 2001).

Research conducted for the UK government's Department of Trade and Industry found that domestic hot water demand varied linearly with number of occupants, and that demand had increased since the BREDEM equation was developed (DTI 2005a). As a result, the following alternative equation was proposed:

$$Q_u = 8.64 \text{ x } 10^{-5} \times (51.85 / 25 \times 40 N)$$

This was used in the present research, and it is assumed that it applies equally to hot water use in the base year 2006. Losses incurred in hot water supply were calculated for each estate based upon the systems for hot water provision installed, and equations from BREDEM (BRE 2001). There is no linkage in the model developed for this research between the level of losses from hot water systems and space heating demand, due to the extra complexity involved in taking this into account.[1] As levels of losses do not differ greatly between the four principal refurbishment approaches considered, this is unlikely to have a significant impact on results.

5.5.3 Lighting

Energy use for lighting is assumed to be a function of the floor area of Peabody dwellings along with the proportion of low energy bulbs fitted. It was modelled using a modified version of the equation given in SAP 2005 (BRE 2006c), which gives an equation for lighting energy use as:

$$E_L = E_B \times TFA \times C_1 \times C_2 \text{ kWh / year}$$

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[1] This is also the case for gains from lighting, cooking and electricity use.

where E_B = 9.3 kWh/m^2; TFA is the total floor area in m^2; $C_1 = 1 - 2/3 \times 3/4 \times N_{LE} / N$ (where N is the number of fixed lighting outlets, N_{LE} the number of fixed outlets fitted with low energy bulbs; C_2 is a correction factor to take into account the effects of daylighting (ranging in value from 0.96 to 1.17 for Peabody estates, based on the equations given in BRE (2006c).

Savings due to energy efficient lighting are modelled using the constant C_1: the fraction 3/4 represents the assumed fraction of energy saved by using a compact fluorescent lamp (CFL) in place of an incandescent bulb; 2/3 represents the fraction of lighting energy consumption coming from fixed outlets. The SAP 2005 equation assumes that CFLs are only installed in these fittings, not in movable lamps.

Under all scenarios considered for the model, it is assumed that incandescent bulbs are phased out in the UK (Defra 2007c), so that all lighting is from energy efficient bulbs by 2015. The SD and PD scenarios assume, following Boardman (2007), that CFLs begin to be phased out from 2015 to be replaced with light emitting diodes (LEDs), which are assumed to use 1/10th of the energy of conventional bulbs (based on Boardman (2007)). The SAP equation is inadequate in this context, as it assumes that one third of all lighting demand is still met with incandescent bulbs installed in movable lamps, and that all energy efficient bulbs are CFLs. As a result, the equation has been modified for the Peabody Energy Model, with C_1 being redefined as

$$C_1 = 1 - (1/3 \times E_y \times NM_{LE} / NM) - (2/3 \times E_y \times N_{LE} / N)$$

where E_y is the fraction of energy saved by an energy efficient light bulb in the year y, and NM_{LE} / NM is the fraction of movable lamps fitted with energy efficient bulbs.

For 2006, N_{LE} / N is assumed to be 0.55, based upon results from the survey of Peabody residents at its residents' conference in 2007 (Appendix E). NM_{LE} / NM for 2006 is assumed to be 0, in line with the SAP 2005 model. Both N_{LE} / N and NM_{LE} / NM increase linearly to 1 in 2015, based upon the assumption that by that date all lamps are CFLs. In the SD and PD scenarios, CFLs are phased out for LEDs from 2015, so that LEDs alone are being used by 2030. The KLO and BD scenarios assume a lower take-up of LEDs from 2015, with 20% of light fittings LEDs in 2030 and 80% CFLs.

Although energy used in the home for lighting has declined slightly since the BREDEM model was published in 2001 (BERR 2008c), there is no strong evidence of a decline in the energy service sought from lighting, so it is assumed that the equation described above specifies demand for energy for lighting for 2006.

5.5.4 Cooking

Energy use for cooking is assumed to be a function of the number of residents in Peabody households. It was modelled using the equations from the BREDEM model, which gives annual energy use E_C in GJ is given as

$$E_C = 1.70 + 0.34\ N, \text{ for cooking with electricity}$$

$$E_C = 2.98 + 0.60\ N, \text{ for cooking with gas}$$

where N is the number of occupants. This is translated into energy use for cooking at the estate level with figures from Peabody for average occupancy for each estate and data on the number of gas and electric cookers from Peabody's stock condition database.

Since 2001 energy use for cooking has declined by 6% (BERR 2008c). The base energy use for cooking in 2006 was therefore calculated using BREDEM equations above, then by reducing the result by 6%.

5.5.5 Other electricity

Demand for "other" electricity, to provide energy for household appliances is assumed to be a function of both the floor area of a home and the number of householders. An equation from BREDEM was used to model demand for other electricity, which gives electricity for lights and appliances in GJ as

$$E_L = E_{LA} - \text{Energy used for lighting} + \text{Energy used for pumps and fans}$$

where $E_{LA} = 4.47 + 0.0232 \times TFA \times N$, and where TFA = total floor area of a dwelling and N = number of occupants

Energy used for pumps and fans was calculated for each estate based upon the energy supply systems installed and using data from SAP 2005. The energy used for lighting in this equation is the energy use given by the original SAP 2005 equation for lighting use, reported above.

Since 2001, electricity demand per household for purposes other than lighting, heating and cooking has increased by 11% (BERR 2008c). This increase was therefore applied to the figure for base demand arrived at using the above equation. In addition, due to evidence of lower electricity use for social housing tenants (Brandon and Lewis 1999), it was assumed that electricity demand for Peabody homes would be lower than that given in the BREDEM equation. A 10% reduction was applied based upon Peabody data from its BedZED estate where consumption has been monitored in 2007 for different tenure types (Bioregional 2008). Taken together these two modifications leave the equation used for electricity demand close to the original BREDEM equation.

5.5.6 Changes in demand

Resident demand for energy is likely to change over coming years, as it is subject to a number of potentially strong influences such as changing consumption patterns, high fuel prices, changes in climatic conditions affecting demand for space heating and cooling (ARUP 2008), or environmental concerns leading to demand reduction. These issues are considered in the model by modifying annual energy use for each category based upon scenario assumptions.

Changes in demand beyond 2006 are modelled in three steps. Initially it is assumed that present trends continue to 2010 for each scenario (i.e. no change in demand for lighting, hot water or heating; annual 1.1% reduction in demand for energy for cooking; annual 1.65% increase in demand for “other electricity”), based on BERR (2008c). Changes in demand are then considered from 2011 to 2016. This is a relatively short period, which is used so that any rapid demand reductions that represent the “low hanging fruit” of energy saving can be captured, and so changes that could allow the goal of eliminating fuel poverty by 2016 to be achieved can be studied. Beyond this date, changes in demand are considered up to 2030. In each case an annual percentage change in demand is considered for each energy use.

The values used for each scenario are given in Table 5.10. The principles used to determine the values used were: present trends continuing in the KLO scenario; behaviour change leading to reduced energy demand up to 2016 in the SD and PD scenarios; high fuel prices leading to reduced energy demand in the PD and BD scenarios from 2016 onwards. The resultant greatest levels of demand reduction considered (in the PD scenario), are towards the upper end of demand reductions that are likely to be realisable through feedback on energy use (Darby 2006) and comparable to the 20% reductions assumed possible in the WWF (2008) study on existing housing refurbishment.

Scenario	Demand for heat, hot water, lighting and energy for cooking		Demand for electricity	
	Annual changes	Change to 2030	Annual changes	Change to 2030
KLO	No change	+0%	1.65% annual increase to 2030	+48%
SD	Annual reduction of 2% from 2011 to 2016, then no change	-11%	No change to 2016, then annual 1% reduction to 2030	-7%
PD	Annual reduction of 2% from 2011 to 2016, then annual 1% reduction to 2030	-23%	No change to 2016, then annual 2% reduction to 2030	-20%
BD	No change from 2011 to 2016, then annual 1% reduction to 2030	-13%	1.65% annual increase from 2011 to 2016, then annual 1% reduction to 2030	+2%

Table 5.10 Changes in energy demand levels

An issue that has not been considered is the impact on energy demand for the period up to 2030 of changes in London's climate. Over the long term, there is increasing evidence that homes will need to be adapted for the impacts of climate change, which could include a reduced need for space heating and increased requirements for cooling as average temperatures increase (ARUP 2008). A number of passive measures such as the use of shading, shutters or green roofs are available to mitigate against over-heating in homes without increasing energy use (ibid), but such adaptation measures are beyond the scope of this research. A more relevant issue for this study is the risk that insulation measures that reduce heat demand may make it more likely that active cooling of dwellings through air conditioning or fans is required in summer months (CIBSE 2005). This is a particular risk where measures such as internal solid wall insulation are installed, due to the reduction in internal thermal mass of dwellings (ibid). These issues were not considered in the model study, due to: the increased complexity involved in modelling the resulting changes in energy demand; the possibility that passive measures could be used to mitigate against over-heating during the relatively short period considered by the model; the possibility that impacts of increased temperatures on overall energy use and CO_2 emissions could be broadly neutral, due to reduced energy use for heating and increased energy use for cooling cancelling each other out to some extent. Nevertheless, this represents a limitation of the present research and implies that findings related to the long-term impacts of insulation measures should be treated with particular caution.

5.6 Efficiency of energy systems

Energy demand is converted into annual fuel use for each estate based upon the assumed energy supply systems installed and their assumed efficiencies, which are given in this section for each technical measure considered. For all technologies, a conservative assumption is made that efficiencies do not improve during the period studied.

5.6.1 Gas Boiler efficiencies

Values for efficiencies are given in Table 5.11. Dwellings without TRVs are assumed to have a 5% reduction in their efficiency for supplying heat (BRE 2006c). As new boilers are installed, a greater proportion of boilers on Peabody estates are condensing boilers, leading to the average efficiency of gas boilers on each estate gradually improving. As a result, by 2018 (after 12 years, the assumed lifetime of a gas boiler) all installed boilers are 90% efficient.

Gas heating type	Efficiency in 2006	Source
Gas heating: Old estates, pre Decent Homes	70%	BRE (2006c)
Gas hot water: Old estates, pre Decent Homes	63%	BRE (2006c)
Gas heating and hot water: Old estates, post Decent Homes	75%	BRE (2006c)
Gas heating and hot water: New estates	83%	BRE (2006c)
New condensing combination boilers	90%	Dwyer (2007)

Table 5.11 Gas boiler efficiencies

5.6.2 Electric heating

Electric heating systems are assumed to be 100% efficient within Peabody dwellings BRE (2006c), although efficiency losses are associated with the production and distribution of electricity prior to its arrival in homes (which are accounted for in the emission factors used for electricity). As is the case for gas-fired systems, there are losses associated with the storage and distribution of electrically-heated hot water, calculated using equations from BREDEM (BRE 2001).

5.6.3 Communal heating efficiencies

Efficiencies for communal heating installations are given in Table 5.12, based upon figures in existing literature or those used by Dwyer (2007). The stated efficiencies for existing communal boilers reflect an assumed loss in efficiency where residents are not billed according to use and where TRVs are not installed.

Boiler Type	Efficiency	Source
Existing communal boilers, pre Decent Homes	65%	BRE (2006c)
Existing communal boilers, post Decent Homes	70%	BRE (2006c)
New communal boilers, new biomass boilers & existing communal boilers, post Fabric package	85%	Dwyer (2007), RAB (2007)
Gas-fired CHP & Biomass CHP	50% heat, 28% electricity	Dwyer (2007)

Table 5.12 Communal heating efficiencies

5.6.4 Solar thermal and solar PV

The annual output per square metre of solar thermal is taken as 400kWh (an average of the figures given in London Renewables (2004) and Croxford and Scott (2006)). For solar PV, it is assumed that polycrystalline panels are installed, with an associated net output (after inverter losses) of 90kWh/m^2 on flat roofs, 88kWh/m^2 on south-facing roofs and 75kWh/m^2 on east and west facing roofs (Whitby Bird & Partners 2001).

5.6.5 Heat pumps

For GSHPs, the coefficient of performance (COP) is taken as 2.4 for heat and 1.68 for hot water (BRE 2006a). For ASHPs, the COP is 1.88 for heat and 1.31 for hot water (ibid).

5.6.6 Ventilation

Where two extractor fans are installed it is assumed they consume 5.5 kWh a year, based upon the lo-watt fans considered by Dwyer (2007).

5.7 Carbon emission factors

Carbon emission factors translate the total energy use for each fuel into figures for carbon emissions, and are given for the base year 2006 in Table 5.13. Following standard practice, system average emission factors are used for calculating emissions due to consumption from the gas and electricity grids (Bettle et al. 2006; Defra 2007e). Where electricity is displaced from the grid through on-site generation, a greater average emission factor is used to calculate the resultant carbon savings, to take account of the relatively higher carbon intensity of marginal plant supplying the grid (discussed further in 5.7.1). The emissions factor for district heating is based upon data provided by Peabody on an existing district heating scheme in London. Woodchips used for biomass boilers were assumed to be carbon neutral. Although there are clearly emissions associated with the transportation and processing of this fuel, supply chain emissions are not considered for other conversion factors, and so for consistency, have not been considered for biomass.

Energy Source	Emissions factor 2006 ($kgCO_2$ /kWh)	Source
Gas	0.204	Defra (2007e)
Electricity	0.527	Defra (2007e)
Displaced grid electricity	0.568	BRE (2006c)
District heating (heat supplied)	0.33 (initial emission factor, considering gas used only)	Based on Peabody experience
District heating (heat supplied)	0.13 (overall emission factor, after consideration of displaced grid electricity)	Based on Peabody experience

Table 5.13 Base carbon emission factors

Changes in emission factor used are given in Table 5.14. For all scenarios, the change for grid electricity up to 2010 is based on projections from the Market Transformation Programme (MTP 2007). Beyond this date, further changes are assumed to differ by scenario. For the KLO and BD scenarios, the reductions projected to 2020 by the MTP (2007) are adopted, and linearly extrapolated on to 2030. For the SD and PD scenarios, greater reductions are assumed, to give a carbon intensity of electricity that falls to around half its 2006 level by 2025. The figure used for 2030 is based upon the low estimate used by the Renewables Advisory Board (2007). The reduction of approximately 50% on current levels, matches the reduction called for in London's Climate Change Action Plan as a step required for London to achieve its carbon reduction targets (GLA 2007). Whilst these assumptions represent a substantial change relative to the present day, they are also relatively conservative when compared to the near-total grid decarbonisation by 2030 called for by the Committee on Climate Change (2008).

No change in emission factor was assumed for the gas network, due to uncertainty about the extent to which biomethane could be incorporated in the gas supply (BERR 2008a). The Conservative party have pledged to work towards 50% of the gas grid being supplied by biomethane over the long term (Conservatives 2009), so this is also a relatively conservative assumption.

For district heating, no change in carbon intensity is adopted in the KLO and BD scenarios, for which it is assumed to continue to be fuelled only by natural gas. The SD and PD scenarios assume a declining carbon intensity of heat from district heating due to increased use of biomass and biogas as fuels. No known projections for take-up of these fuels for district heating in London exist, although there is an existing precedent of 36% of energy for district heating in Denmark being supplied by biofuels (ten Donkelaar 2007). Based upon this figure, an optimistic assumption was made that by 2030, one third of the fuel used for district heating is renewable in the SD and PD scenarios.

The overall carbon emissions associated with district heating also take into account the carbon emission reductions associated with displacing grid electricity, which decline in each scenario up to 2030 as the carbon intensity of grid electricity declines (discussed in 5.7.1). This has the impact of making the carbon emission factor associated with district heating greater than it would be otherwise.

Energy source	Scenarios	Period	Change per year ($kgCO_2/kWh$)	Source
Electricity	All	2006–2010	-0.00175	Based on MTP (2007)
Electricity	KLO & BD	2011–2030	-0.0099	Based on MTP (2007)
Electricity	SD & PD	2011–2030	-0.01745	Based on GLA (2007)
District Heating	SD & PD	2006–2030	-0.0046	Assumed

Table 5.14 Changes in carbon emission factors

The resultant carbon intensity of the energy sources considered is illustrated in Figure 5.4. The graph shows that from 2028, electricity has a lower carbon emission factor than gas in the SD and PD scenarios, illustrating the potential for grid decarbonisation to reduce the relative effectiveness of gas as a low-carbon fuel.

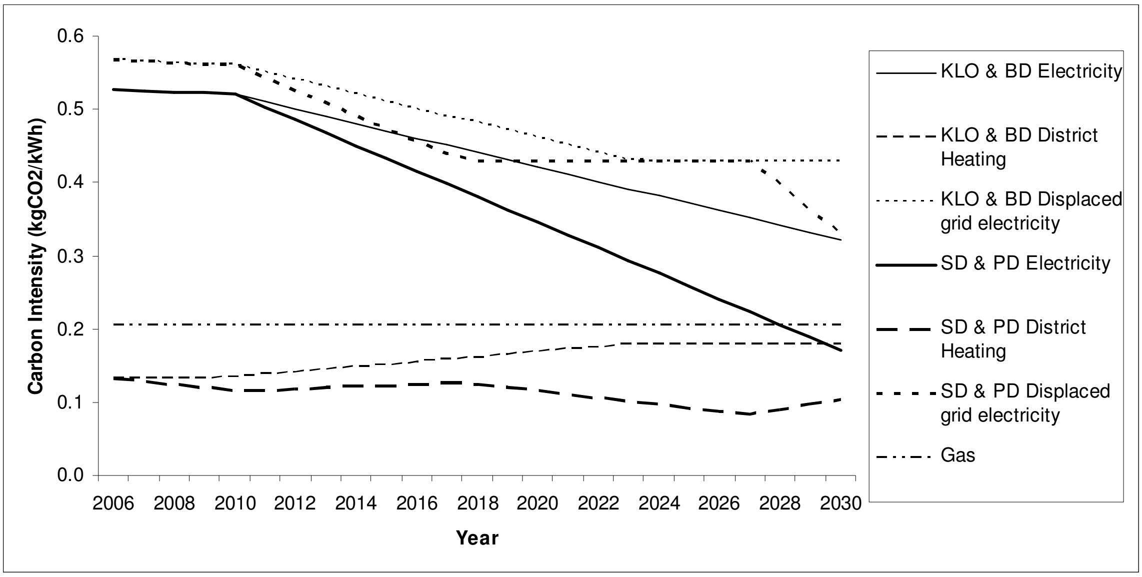

Figure 5.4 Carbon Intensity of electricity, gas and district heating

5.7.1 Displaced Grid Electricity

The approach taken to grid electricity supplies displaced by generation on estates requires particular attention due to the conflicting approaches found in existing literature. This assumption can have a significant impact on the modelled impact of low carbon technologies (UKGBC 2008b).

Prior research on the carbon intensity of the electricity grid has identified that the marginal plant supplying the grid differs seasonally, between weekdays and weekends and during the course of a day (depending on demand levels) (Bettle et al. 2006). As a result, for technologies with distinct generation profiles (for example, solar PV will predominantly generate electricity during the daytime, peaking in output during the summer) there is a case for using distinct values for the carbon intensity of displaced electricity to take this into account. The study by Bettle et al. (2006) which addressed this question for a number of demand reduction measures was unable to identify general rules to take these issues into account. As a result, it recommended using a single average carbon intensity figure for displaced grid electricity where several demand reduction measures are considered (ibid). This is the approach taken in the present study.

For the base year 2006, it is assumed that where electricity is generated by solar PV or CHP and exported to the grid, net carbon emissions are reduced by 0.568 kg CO_2 for each kWh generated (BRE 2006c). This figure is greater than the grid intensity assumed for electricity use (0.527 kg CO_2 per kWh), as it is based upon the principle that the use of the more carbon-intensive marginal plant used to provide for extra demand (coal and gas fired power stations) is being reduced. As a result, an estate where fossil fuels are used (for example, gas as fuel for condensing boilers) can still achieve zero net carbon emissions if sufficient on-site generation takes place.

An issue considered by this research is the potential for the carbon intensity of grid electricity to approach or reach zero. If the grid produces zero-carbon electricity, a reduction in net emissions for any electricity generated would no longer be appropriate, as any displaced grid electricity would be from a zero-carbon source.

Where a pathway from the original grid carbon intensity of 0.527 kg CO_2 per kWh towards zero is assumed, there is therefore a need to put forward a pathway for the carbon intensity of displaced grid electricity that arrives at the same end point (zero) at the same time. This consideration gives rise to a number of approaches for accounting for the carbon intensity of grid electricity (Figure 5.5).

One possible approach would be to assume that displaced electricity has the same carbon intensity as any electricity used. This approach was rejected as it does not take into account the extra benefit achieved through micro-generation of displacing the more carbon-intensive marginal capacity of the grid.

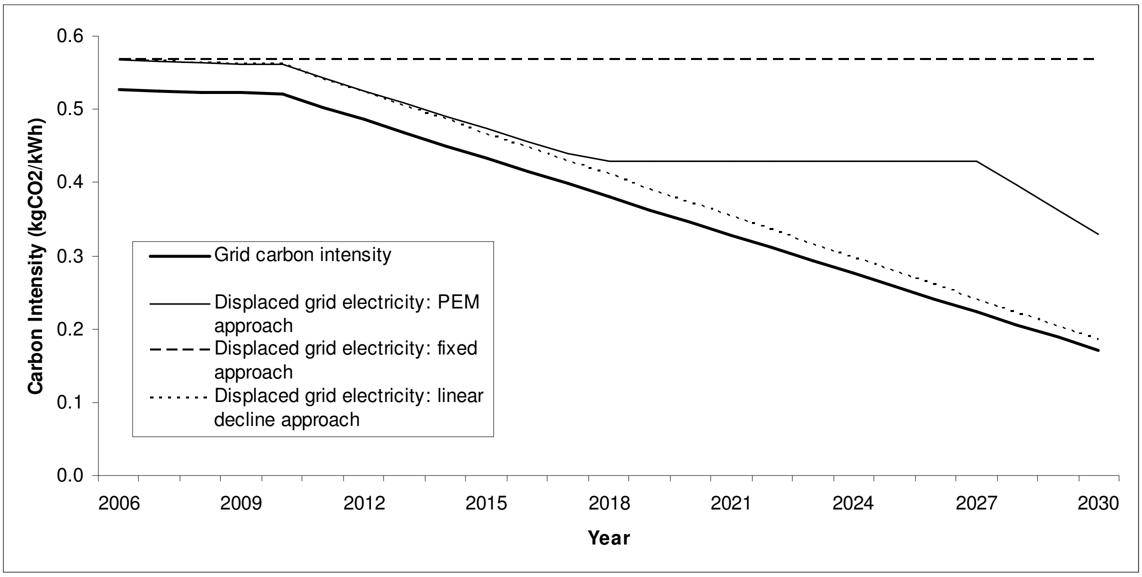

Figure 5.5 Approaches to displaced grid electricity

A second approach considered was to simply assume that the carbon intensity of displaced grid electricity declines linearly towards the same zero end-point. This approach was also rejected as it did not accurately capture the nature of the carbon intensity of displaced electricity. Once a point is reached where the marginal plant supplying the grid is the most efficient combined cycle gas-turbine power stations, further input of renewables into the grid over the following years is unlikely to provide further reductions on the carbon intensity of displaced electricity, as the marginal plant would be unchanged.

Another approach that was rejected was to assume that the carbon intensity of grid electricity does not change at all, an assumption used in other research in this area (for example, in RAB (2007)). This is not consistent with either the reduction in emissions savings associated with displacing marginal plant as generation through gas-fired power stations replaces coal, or with the possibility of a zero carbon grid.

The approach that was adopted describes a carbon intensity of displaced electricity that initially declines at the same rate as for grid electricity, until it reaches the value of 0.43 kg CO_2 per kWh, the figure assumed for efficient gas-fired power stations (Defra 2007d). It then plateaus as these power stations remain the source of marginal supply, despite further renewables being used to supply the grid. Assuming a pathway to a zero-carbon grid, at some point the displaced electricity carbon intensity must start declining again, as a qualitative change to the supply of electricity begins to take place. There is little research done to date on how this process could happen, although a pathway towards a zero-carbon grid in the UK has been advocated in existing research (CAT 2007; CCC 2008). This research assumes that when the grid has a carbon intensity of 0.225 (notionally 50% from combined cycle gas-fired power stations, and 50% from zero-carbon sources), this change commences, starting a linear decline towards zero carbon electricity.

Although this approach is based on some simple assumptions on the nature of electricity supply in the context of a substantial proportion of grid electricity coming from zero-carbon sources, it is put forward as a more realistic approach than either the “fixed” approach (assuming no changes in the carbon intensity of displaced grid electricity), or the “linear decline” approach (assuming a linear pathway towards eventual zero carbon emissions). The impacts of using the latter two approaches were however considered as part of the sensitivity analysis.

5.8 Fuel costs

Figures for the use of fuels on Peabody estates were translated into spending on fuel for Peabody and its residents using assumptions regarding fuel prices. This section reports the assumptions used to calculate base fuel costs for Peabody and its residents (5.8.1), base fuel costs where Peabody sells energy to residents (5.8.2), and changes in fuel costs over future years (5.8.3). Financial support for energy generated through micro-generation, such as feed-in tariffs, is discussed in section 5.8.4.

5.8.1 Unit costs and standing charges

For Peabody residents, the price paid for fuel can vary significantly depending upon the supplier used, the type of tariff and the method of payment. This research assumes that an average price is paid by all residents, based upon standard tariffs for gas and electricity and quarterly payment in arrears. This assumption is intended to provide a reasonable average figure, taking into account that some residents could be paying lower prices due to social tariffs, dual-fuel discounts or payment by direct debit, whilst those with prepayment meters could be paying higher prices. Gas prices from British Gas and electricity prices from EDF were used, as these were the suppliers in the London area prior to energy supply being opened up to competition, and are therefore the most likely suppliers to be used by Peabody residents.

Data from these companies indicates that gas and electricity are sold at a higher unit cost for an initial band of units (usually 5860 kWh for gas, 900 kWh for electricity), then a lower unit cost. To incorporate this efficiently within the model, gas and electricity costs were modelled using a “proxy standing charge” (DTI 2006), given by the equation

$$\text{Proxy standing charge} = U \times (C_1 - C_2)$$

where U is the usage in kWh for the initial band of units, C_1 is the unit cost for these units, and C_2 is the unit cost of subsequent units. Costs are then calculated as the proxy standing charge plus any usage multiplied by C_2 (see Figure 5.6).

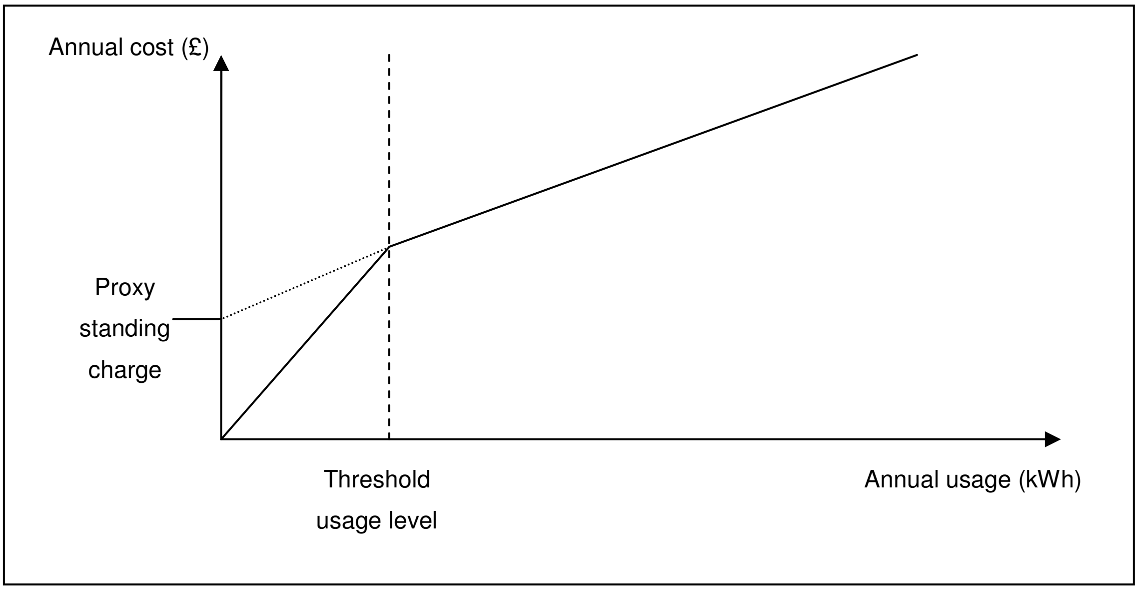

Figure 5.6 Proxy standing charge

The proxy standing charge approach provides accurate results as long as the threshold usage level is exceeded (if not, it will lead to an over-estimate as Figure 5.6 illustrates). This is likely to be the case for all dwellings using gas except for where homes have gas cookers only (for example, after individual gas boilers are removed in favour of communal heating). For these dwellings, it is assumed that no standing charge applies and all gas use is charged at the higher initial rate. Values for base proxy standing charges (Table 5.15) and gas and electricity costs (Table 5.16) were calculated using data on October 2008 costs from British Gas (for gas) and EDF Energy (for electricity). For the year 2006, where average annual fuel costs are £581 for Peabody estates, the proxy standing charge totals £151, equating to 26% of average resident costs.

Information on price increases from 2007 to 2008 from the Energylinx website (Energylinx 2008) were used to convert these prices to 2007 levels. Information from BERR on changes in gas and electricity costs from 2006 to 2007 (BERR 2008b) was then used to convert prices to 2006 levels. Price conversions were based upon annual average consumption figures used by BERR of 3300kWh for electricity and 18000kWh for gas (BERR 2008b).

Fuel	Proxy standing charge	Source
Gas / communal heating	£100.50	British Gas(2008), BERR (2008b), Energylinx (2008)
Standard electricity	£50.50	EDF (2008), BERR (2008b), Energylinx (2008)
Economy 7 electricity	£63.30	EDF (2008), BERR (2008b), Energylinx (2008)

Table 5.15 Proxy standing charges

Fuel	Cost 2006 (£/kWh)	Source
Gas	0.021	British Gas (2008), BERR (2008b), Energylinx (2008)
Standard electricity	0.088	EDF (2008), BERR (2008b), Energylinx (2008)
Economy 7 (day)	0.095	EDF (2008), BERR (2008b), Energylinx (2008)
Economy 7 (night)	0.038	EDF (2008), BERR (2008b), Energylinx (2008)
Heat pump electricity	0.076	Based on Ryedale Energy Conservation Group (2007)
Gas tariff for initial units	0.036	British Gas (2008), BERR (2008b), Energylinx (2008)
Peabody gas	0.023	Based on British Gas (2008), BERR (2008b), Energylinx (2008) and Peabody experience
Peabody electricity	0.086	Based on EDF (2008), BERR (2008b) and Peabody experience
Peabody biomass	0.025	RAB (2007)

Table 5.16 Base fuel costs

For Peabody's purchases of gas and electricity it is assumed that a bulk purchase arrangement can be made with a utility company so that Peabody pay a fixed rate per unit used, without incurring standing charges. At present, Peabody has such an agreement for gas and electricity supply to estates, and the costs assumed were based upon these figures. Despite having a higher unit rate in the case of gas, this assumption can give Peabody an overall saving on purchases of gas and electricity relative to residents as, unlike its residents, it pays no standing charges. Where heat pumps are installed, it was assumed that economy 7 meters are used, with 2/3 of use taking place overnight and 1/3 of use during the day (Ryedale Energy Conservation Group 2007).

5.8.2 Sales to residents

For all sales of energy to residents, it is assumed that the sale price cannot leave residents with higher bills than if they are purchasing gas or electricity from the grid, following current practice used in billing residents by Peabody. Furthermore, in order to identify the most cost-effective approach from Peabody's perspective, it is assumed that both the cost of heat and electricity are set at the maximum possible level, so that residents pay an equivalent amount to Peabody as they would to a utility company.

The cost for heat from communal heating for residents is the cost per kWh of delivered heat (for space heating and hot water), not the cost per kWh of gas consumed, as is typically the case where individual gas boilers are used. As gas boilers are not 100% efficient, units of heat can therefore be sold at a marginally higher price than units of gas, without leaving residents worse off overall. Assuming that gas condensing boilers are installed with an efficiency of 90%, the unit price of gas (£0.021, from Table 5.15) is initially multiplied by 100/90 to give a maximal unit price for heat sales that takes this into account. The sale price for heat is further modified by considering that after communal heating is installed, residents are likely to continue to use gas cookers in their homes (based upon the views of Peabody staff). As the resulting gas use would all be charged at the higher initial unit rate, residents receiving communal heating would be worse off overall by the approach to pricing described above (paying the same for heat and hot water, but more for cooking). It is therefore assumed that heat is sold to residents with a 10% discount on the maximum possible rate, which leaves the overall unit cost for heat the same as that assumed for gas (Table 5.17). This assumption leaves residents with overall costs that are largely unchanged after receiving a communal heating connection. Electricity sales are simply priced at the same level as electricity from the grid.

Energy Source	Cost 2006 / £/kWh
Heat (from Communal or District Heating)	0.021
Electricity	0.088

Table 5.17 Prices for energy sales to residents

5.8.3 Changes in fuel costs

The assumed changes for both standing charges and unit costs are given in Table 5.18. Based upon changes in gas and electricity prices in recent years, the proxy standing charge is assumed to stay constant in real terms for gas, and to increase at the same rate as unit costs for electricity.

Fuel	Annual increase in price	Source
Gas units (2006-2007)	17%	British Gas (2008), BERR (2008b)
Gas units (2007-2008)	15%	British Gas (2008), BERR (2008b)
Electricity units and standing charge (2006-2007)	6%	EDF (2008), BERR (2008b)
Electricity units and standing charge (2007-2008)	13%	EDF (2008), BERR (2008b)
Gas units (2008-2030)	1% (KLO); 1.5% (SD); 2.5% (PD); 3.5% (BD)	Scenario assumptions
Electricity units (2008-2030)	1% (KLO); 2.5% (SD); 3.5% (PD); 3% (BD)	Scenario assumptions
Biomass (2006-2030)	As for gas	Scenario assumptions

Table 5.18 Annual Changes in fuel costs

From 2006 to early 2008, gas and electricity prices have risen substantially. Changes during this period are based upon data from utility companies and BERR (2008b). From 2009 to 2030, changes are based upon assumptions made for each scenario. Fuel price changes for this period are challenging to predict, although most analysts expect prices to increase in real terms. Estimates of possible changes in existing literature include an increase of around 2% per annum for gas (Powry Energy 2007), 1% annual increases for gas and 3% for electricity (BERR 2008a), and annual increases for gas and electricity of between 3.5% and 10% (Croxford and Scott 2006). In recent years changes in gas prices have been accompanied by relatively smaller changes in electricity prices (BERR 2008b).

Annual price increases at the high end of the range given above (towards 10%) were not used for this research due to the substantial rise in fuel prices this leads to by 2030. For example, an annual increase of 7.5% in gas prices from 2008 to 2030 leads to 2030 prices being around five times 2008 levels. Increases on this scale do not fit with any of the defined scenarios, which are not intended to represent extreme changes relative to present conditions. Furthermore, since 1970 gas and electricity prices expressed in real terms have remained within 50% of 1990 prices, which approximates an average price over that period (Figure 5.7, based on BERR (2008c). Therefore, although significant price increases have been projected by many analysts there is no precedent in recent decades of fuel prices going through a many-fold increase.

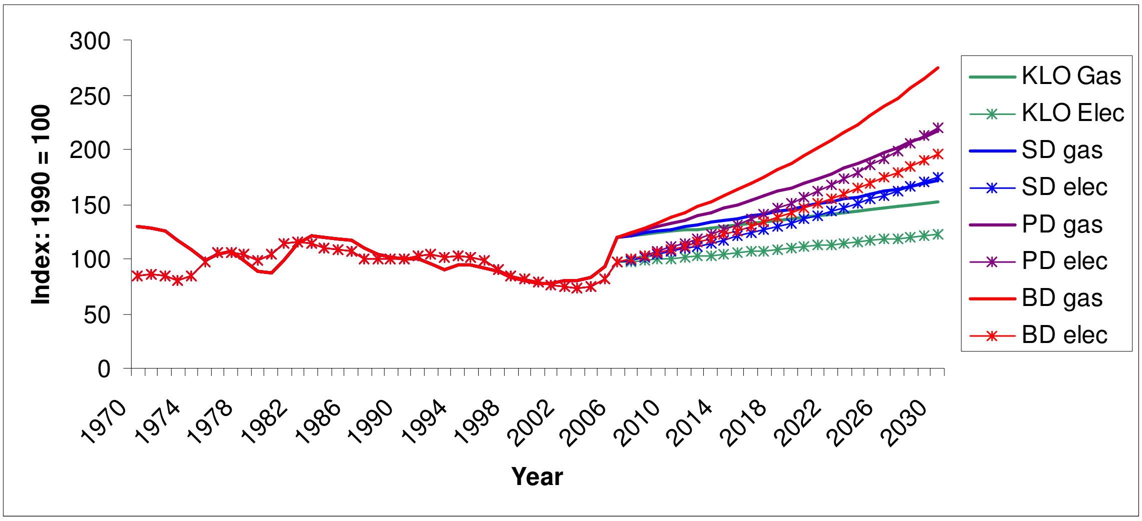

Figure 5.7 Historical and scenario-specific fuel prices relative to 1990 levels

Given these issues, the increase in prices for gas and electricity for each scenario were based upon relatively low annual increases (Table 5.18). Nevertheless, for the highest fuel price scenario, BD, this led to prices for gas approximately doubling relative to 2008 levels, or nearly tripling relative to 1990 levels. For the KLO and BD scenarios, it was assumed that the recent trend for gas prices to rise at a greater rate than electricity prices continues. For SD and PD, it was assumed that the greater investment in new renewable infrastructure for electricity generation led to electricity prices rising at a greater rate.

For simplicity, a smooth increase in fuel prices is assumed for each scenario to represent the broad long-term trend, although in practice, as the historical record shows, there is likely to be considerable fluctuation in prices around any broad trend over the coming decades. There is a possibility that changing the assumptions on fuel price changes could significantly affect model results for each scenario, so this potential was explored through sensitivity analysis. Biomass prices are assumed to increase at the same rate as gas prices, due to competition between the two fuel sources and current practice of offering long-term biomass contracts with prices indexed against those of gas or oil (Welsh Biofuels 2008).

5.8.4 Support for micro-generation

Since the modelling work was carried out for this research, feed-in tariffs (FITs) have been endorsed by the UK government as a system to support take-up of micro-generation technologies (DECC 2008). FITs reward generation of low-carbon energy by paying a tariff to generators, with the rate depending on the technology installed and its installation date (BMU 2007). A proposed method for implementing FITs in the UK, including high payments for the initial output of any installation, has recently been put forward by the Renewable Energy Association (REA 2009). The Government has yet to state its preferred approach for implementing FITs, or the rates that will apply for particular technologies. Updating the model design to take into account the method of implementing FITs proposed by the Renewable Energy Association in 2009 was not possible. The support for micro-generation modelled (either the present renewable obligation system or FITs with much lower rates than those proposed in REA (2009)) therefore does not take into account the recent proposals put forward for making investment in micro-generation much more cost-effective.

The model assumes that FITs are brought in to support solar PV from 2011 in the SD scenario, and the current UK approach of incentivising generation of renewable electricity through the renewables obligation is used in other scenarios. The assumed tariff rate and depreciation rate used is based upon current values used in Germany (Table 5.19), converted from Euros into pounds at an exchange rate of 1€ = £0.7 (Exchange Rates

2008). One bulk payment is assumed to be received in the year of installation to cover an assumed 10-year lifespan of the installed technologies, following a delivery approach suggested in DECC (2008). In the remaining scenarios, the base income received through the Renewables Obligation is taken as £41.66 per MWh generated, based upon Peabody income in 2006, and this figure is assumed to stay constant in real terms to 2030. For the SD and PD scenarios, a Renewable Heat Obligation (RHO) is assumed, as proposed by the UK government (BERR 2008a), which rewards generation of renewable heat (through solar thermal or biomass boilers) by paying 2p for each unit of heat generated.

Base rate / £/kWh	Depreciation rate	Source
0.345	5%	BMU (2007)

Table 5.19 Feed-in tariff rate for PV

All scenarios make the original assumption that electricity is sold to residents on estates where CHP is installed. This approach maximises income in the current context, as a low price is currently paid for exports of electricity to the grid. It has the organisational implication for Peabody that it is responsible for supplying energy to its residents. It is therefore assumed that, as is current practice on the BedZED estate, an intermediary organisation is used to provide a billing and metering service. Furthermore, it is assumed that electricity meters and the internal distribution wiring on estates are purchased from the local electricity network operators. If electricity from CHP is instead assumed to be sold to the grid, the latter costs are not incurred. Where electricity is sold to residents, it is assumed that 50% of any electricity generated on Peabody estates is used onsite and the remaining 50% is exported to the grid (EST 2007b). A maximum of 80% of resident electricity demand on an estate is assumed to be supplied through onsite generation, due to the inevitability of some mismatching between generation and demand (Wright and Firth 2007). Where PV alone is installed, it is assumed that all electricity generated is exported to the grid, as is current practice for existing PV installations at Peabody (exports are more lucrative for PV than CHP due to Renewables Obligation support).

5.9 Costs of Measures

The capital and maintenance costs of measures were used alongside assumptions on installed technologies, their rate of replacement, and assumed grant support to calculate Peabody's annual expenditure on its stock. This section gives the costs assumed for fabric and individual servicing measures (5.9.1) and renewables and communal measures (5.9.2), the assumed lifespans of measures (5.9.3) and assumptions on grant funding (5.9.4).

5.9.1 *Costs for fabric and individual servicing measures*

The costs associated with fabric measures and individual servicing measures are given in Table 5.20. This data was obtained from Peabody where available and from literature on housing refurbishment where not. All costs were checked for reliability with Peabody's cost consultants, and some original assumptions were changed as a result. To calculate the cost for each measure, the basic installation cost (the "works cost") was used as a starting point. Following standard practice at Peabody, the works cost was then supplemented by allowances for Preliminaries (contractor costs and site management), Professional Fees, Contingency Costs and VAT, to generate an estimate of the total cost associated with the measure. Preliminaries and Fees apply to any new physical measures that are installed, and contingency costs and VAT apply to all refurbishment spending. A Preliminaries rate of 35% was applied to works costs for measures external to dwellings, and 20% for internal measures. Fees of 15% were then applied to the new subtotal, followed by an additional 10% for contingency costs, followed by VAT. A lower VAT rate of 5% was applied to insulation measures, heat pumps, solar PV and solar thermal installations (HM Revenue and Customs 2006). It is assumed that these costs do not change in real terms during the period 2006 to 2030.

Measure	Works cost	Total cost	Source
Double-Glazing	£507 / m^2	£1017 / m^2	Dwyer (2007), Peabody
External Insulation	£105 / m^2	£188 / m^2	Dwyer (2007), Peabody
Internal Insulation	£70 / m^2	£112 / m^2	Dwyer (2007), Peabody
Floor insulation	£55 / m^2	£88 / m^2	Dwyer (2007), Peabody
Gas Boiler Installation	£3100 / unit	£5529 / unit	RAB (2007), Peabody
Gas Boiler Replacement	£2200 / unit	£2844 / unit	RAB (2007), Peabody
Gas Boiler Maintenance	£110 / yr	£142 / yr	Dwyer (2007), Peabody
Storage Heater Installation	£3100 / unit	£5529 / unit	Based on RTA (2003), Peabody
Storage Heater Replacement	£2200 / unit	£2844 / unit	Based on RAB (2007), RTA (2003), Peabody
Storage Heater Maintenance	£10 / yr	£15 / yr	Assumed nominal cost
Gas cooker Maintenance	£35 / yr	£52 / yr	Based on Peabody experience
Mains Gas Connection	£850 / unit	£1516 / unit	RAB (2007)
TRV Installation	£150 / unit	£239 / unit	Dwyer (2007), Peabody
Heat exchanger, metering and controls installation	£1500 / unit	£2391 / unit	Based on Peabody data
Extractor Fans installation	£500 / unit	£892 / unit	Dwyer (2007), Peabody
Decanting residents[1]	£2800 / unit	£4162 / unit	Peabody

Table 5.20 Installation costs of measures

[1] "decanting" refers to moving residents to temporary accommodation whilst improvements are carried out

5.9.2 *Costs for renewables and communal measures*

Installation costs of renewables and communal heating systems were based upon a combination of fixed costs per dwelling receiving the measure, and variable costs depending upon the size of installation (Table 5.21). Works costs taken from Peabody or literature on refurbishment were transformed into total costs in the same way as reported above.

For communal heating systems and district heating, the fixed cost includes all pipework, heat exchangers and heat meters. Due to the assumption that heat demand is reduced through fabric improvements prior to communal heating installations, the fixed costs dominate the total installed communal heating costs, giving typical costs for CHP and biomass boilers of around £5500 per dwelling.

Measure	Fixed cost	Variable cost	Annual maintenance cost	Source
Solar PV	n/a	£986 /m^2	£7.1 /m^2	Based on Defra (2007e), RAB (2007), DTI (2005b) & Peabody experience
Ground Source Heat Pumps	£13548 / unit	n/a	£57 / unit	Housing Corporation (2008), RAB (2007)
Air Source Heat Pumps	£8378 / unit	£279 per kWth	£57 / unit	RAB (2007)
Solar Thermal	£2690 / unit	£1284 / kWth	£57 / unit	RAB (2007)
Communal Gas Boilers	£1580 / unit	n/a	£37 / unit	Based on Peabody experience
District Heating	£7690 / unit	n/a	n/a	RAB (2007), Peabody experience
Gas CHP	£4459 / unit	£2230 / kWe	£114 / unit	RAB (2007)
Biomass Boiler	£4459 / unit	£731 / kWth	£37 / unit	RAB (2007)
Purchase of private wires	£277 / unit	n/a	n/a	EEBPP (1999)
Purchase of electricity meters	£26 / unit	n/a	n/a	EEBPP (1999)
Billing residents	£52 / unit	n/a	n/a	Peabody experience

Table 5.21 Costs of renewable and communal measures

For solar PV, ground and air source heat pumps, solar thermal and biomass CHP, it was assumed that future installation costs fall over time due to learning on the part of the actors involved in their manufacture and installation (Hinnells 2005). Where the principle of learning is applied, reductions in costs are assumed to increase with the total number of installations of a technology (ibid), so the values assumed for learning rates differ between scenarios with differing take-up of micro-generation (Table 5.22). The figures used for each scenario were based upon the rollout of micro-generation either exceeding or failing to meet the levels projected by the Renewables Advisory Board (2007), leading to a learning rate either 1.5% above or below those given in their study.

	KLO & BD	SD & PD	Source
Photovoltaics	-2.5% / yr	-5.5% / yr	Based on RAB (2007)
Solar thermal and Heat Pumps	-1% / yr	-4% / yr	Based on RAB (2007)

Table 5.22 Learning rates for renewables

5.9.3 Lifespans

The lifespans of measures are an important consideration for the financial assessment of refurbishment, affecting both NPV calculations (5.10) and when replacement installations are required. The figures used are given in Table 5.23.

Measure	Assumed Lifespan (years)	Source
Gas condensing boiler	12	Defra (2007e)
Electric storage heater	20	EST (2007c)
Communal heating systems	15	CIBSE (1999)
Solid wall insulation	30	Based on Dwyer (2007)
Glazing	20	Defra (2007e)
Heat Exchangers and Heat Meters	30	Based on Peabody data
TRVs and Fans	15	Dwyer (2007)
Loft Insulation	30	Dwyer (2007)
Floor Insulation	30	Based on Dwyer (2007)
Communal heating pipework	30	Based on Dwyer (2007)
Photovoltaics	25	Defra (2007e)
Solar Thermal	25	Defra (2007e)
Ground Source Heat Pumps	20	Defra (2007e)

Table 5.23 Lifespans of measures

5.9.4 Grant funding

In the SD and PD scenarios, the Low Carbon Zone funding introduced in section 5.4.3 is assumed to be available for a proportion of Peabody estates. Boardman (2007) assumes that 20% of social housing receives this funding. This figure is approximated in the SD scenario (with 21% of homes treated), and exceeded in the PD scenario which has a stronger focus on insulation measures (30% of homes treated).

For homes not in Low Carbon Zones, grant funding is assumed to be available for all micro-generation installations (solar PV, solar thermal, GSHPs, ASHPs and biomass boilers) for the duration of the period studied. The fraction of installation costs covered differs by scenario: 5% for KLO and BD; 20% for PD; 30% for SD. These figures may appear relatively low when compared to the grant funding of the order of 40% currently available through the Government's Low Carbon Buildings Programme for micro-generation measures. However as political pressure to decrease grant funding is likely to increase over time in scenarios defined by high take-up of micro-generation, funding levels of up to 30% throughout the period from 2011 to 2030 may be towards the upper end of what is achievable in practice. The upper limits of grant funding considered are of the same order as the maximum levels considered in two major recent studies on the take-up of micro-generation in the UK (DTI 2005b; EST 2007b).

5.10 Costs for Peabody

This section describes the model outputs used to quantify costs for Peabody, and a description of how net present value (NPV), the principal output used, was calculated. The outputs used are first summarised (5.10.1), followed by the methods used to calculate NPV (5.10.2), the discount rates used in these calculations (5.10.3), and how a price was put upon carbon emissions in NPV calculations using Defra's "Shadow Price of Carbon" (5.10.4).

5.10.1 Model outputs used

The model outputs used were chosen to reflect the financial models employed by social landlords to assess the implications of stock investment. Three related but distinct models were described in a report by Mazars (2005a): an *investment appraisal*, used to allow comparison between alternative possible investments; a *business plan cash flow*, to assess the impact on a business's bank balance over future years; a *valuation*, to take into account the amount that could be generated by disposing of assets relevant for the investment decision.

For the appraisal of potential investments, calculating NPV and contrasting results between options is the most strongly recommended approach in literature on business finance (McLaney 2003; Ryan 2007), and was therefore used for this research. Further explanation of the methods used and rationale behind them is given in 5.10.2.

Analysis of alternatives using NPV alone does not necessarily indicate that the preferred alternative is realisable by an organisation, as it does not explicitly consider the viability of the considered cash flows in terms of the organisation's business plan (Mazars 2005b). The difference in net expenditure up to 2030 for each refurbishment approach relative to the Base approach was therefore also calculated to take this into account, and used in discussions with Peabody staff on the financial viability of investment.

Consideration of the value of assets (as measured in Peabody's accounts) would potentially strengthen the financial argument for refurbishment, particularly for fabric measures, where improvements could result in a sustained increase in the value of treated properties. Such increases in value would however be unlikely to be translated into cash flows for Peabody because, like other social landlords, they would be unlikely to either increase rents as a result or sell the improved homes. As a result, the value of Peabody's assets was not calculated for the PEM study, as the issue seemed unlikely to significantly affect refurbishment decisions, and would have required a more complex model if it was to be taken into account. However, the increased value to Peabody of having installed technical interventions (such as solar PV) in 2030 with a lifespan beyond that date was taken into account in NPV calculations through the use of terminal values (5.10.4).

Each of the decisions taken above was made in consultation with staff from Peabody's finance department, to ensure that the study would produce valid and useful results from Peabody's perspective. In addition to the outputs above, capital costs of refurbishment options were also calculated to provide a comparison with other research on the costs of carbon reduction refurbishment.

5.10.2 NPV

NPV is calculated by summing cash inflows and outflows for each year during the assessment period (2011 to 2030), and applying a discount rate to these figures to take into account the reduced weight attached to spending and income the later they occur (5.10.3).

A positive NPV is typically viewed as a sign that an investment is beneficial and should be made, whilst a negative NPV indicates an investment that should be avoided. For investments considered as part of this research, NPV values are calculated for the Fabric, Communal and Renewables approaches *relative to the Base approach*. They therefore represent the extra monetary value that is generated by a particular more-extensive approach (if it is positive), or the resulting reduction in value (if it is negative).

NPV is calculated for both Peabody and its residents as a whole (referred to as "NPV"), and for Peabody alone (referred to as "Peabody NPV"). The former approach is used to identify the most cost-effective measures for carbon emission reduction, regardless of split incentives between resident and landlord (2.7.2.2). A positive NPV in this case indicates a "social case" for the refurbishment approach, indicating that Peabody and its residents are better off overall. The latter method is the more traditional application of NPV, used to measure whether it is in the financial interests of Peabody as a business to make a particular set of investments. A positive NPV in this case indicates a “business case” for refurbishment. A negative NPV would indicate that further funding is required to make a refurbishment approach financially viable for Peabody.

It is possible for a refurbishment strategy to have a positive NPV and a negative Peabody NPV. For example, this would happen if the financial benefits of refurbishment to residents outweighed the extra costs incurred by Peabody (as would be likely for measures such as cavity wall insulation). In this case, the positive NPV indicates that by redistributing the financial benefits between Peabody and its residents (for example by increasing rents in refurbished homes), it should be possible in theory to find a solution that financially benefits both parties.

Each measure of NPV is defined by the following equation:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t}$$

where: t = years since start of investment period, N = length of the investment period, r = discount rate, C_t = net cash flow (total income subtracted by total expenditure) in year *t.*

An example NPV calculation is illustrated in Table 5.24. An initial investment of £1000 with a lifespan of 5 years, leads to a net cash flow of £200 in real terms for each of the following 5 years. Summing the cash flows gives the investment a total value of £0 over the 5 years, indicating that it generates neither a profit nor a loss. If a discount rate of 3.5% is used, to reflect the extra weight given to cash flows nearer to the present day, the discounted net cash flow for each year indicates a declining value attributed to the annual £200 cash flows. The total NPV of the investment, taking into account these discounted cash flows is then negative, -£97, indicating that the investment is not financially beneficial.

Year	0	1	2	3	4	5	TOTAL
Net Cash Flow	-£1000	£200	£200	£200	£200	£200	£0
Discounted Net Cash Flow	-£1000	£193	£187	£180	£174	£168	-£97

Table 5.24 Example NPV calculation

The cash flows considered in the NPV analyses are illustrated in Figure 5.8. For Peabody NPV, all cash flows except resident fuel costs are considered. For NPV, all cash flows except those within the dotted lines (energy sales to residents) are considered. Any extra financing costs that could be incurred by Peabody to secure investment capital (i.e. interest on borrowing) are not considered in the NPV assessment. The Shadow Price of Carbon is not used for the original NPV calculations, but its inclusion is assessed in chapter 6.

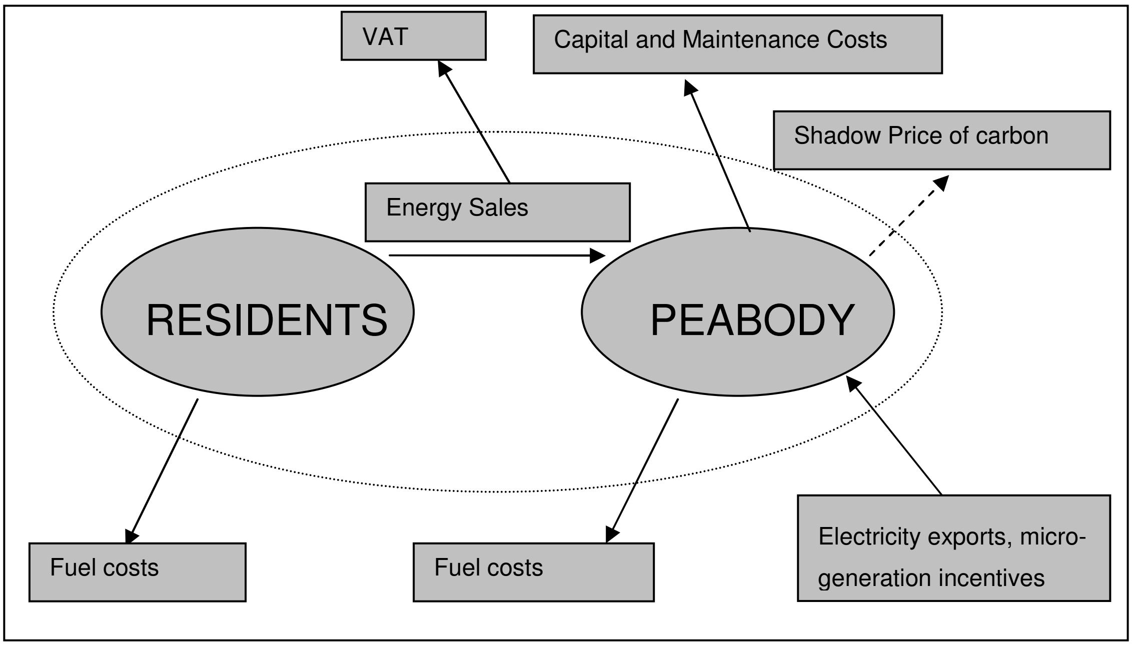

Figure 5.8 Cashflows for residents and Peabody considered for NPV analysis

5.10.3 Discount rates

Discount rates are used to take account of the time value for money — namely that the value of future cash flows to an individual or organisation is not the same as their present day value, and that typically, future cash flows are perceived as of less value (McLaney 2003). For public sector investment decisions, the UK Government Treasury recommends taking this into account using a discount rate of 3.5% (to discount future cash flows as per the NPV equation given above) (HM Treasury 2007).

The 3.5% figure comes from two considerations: assumed growth in the UK economy (contributing 2%), and assumptions of a preference for consumption now rather than in the future, both for its own sake ("pure time preference") and due to a perceived risk that future benefits may not be realised ("catastrophe risk"), contributing 1.5% (ibid). There is considerable debate in academic literature about the appropriate level for discount rates, and arguments have been put forward that the social discount rate should be higher by around 1-3% (Kula 2006) or lower by a similar amount (Mertens and Rubinchik 2006).

For this research, the discount rate used in the KLO and SD scenarios is the Treasury rate of 3.5%, in line with current Peabody practice and consistent with the economic growth levels assumed in those scenarios. For the PD and BD scenarios, assumed lower levels of economic growth lead to lower assumed discount rates (2% and 1.5% respectively). Debate around appropriate discount rate levels is taken into account by using rates of 2% above or below the original assumptions in the sensitivity analysis.

5.10.4 Terminal Values

The NPV calculations carried out for the Peabody model are atypical, as many investments are modelled which require significant capital expenditure, but are only installed for a fraction of their lifetime before the end of the 2011–2030 assessment period. If only expenditure and income during the assessment period was considered, this would tend to generate a bias against strategies involving capital-intensive measures such as solar PV, which would continue accruing savings beyond the 2030 horizon.

To overcome this effect, an approach was devised with staff from Peabody's finance department where a terminal value is calculated for all measures, representing the fraction of the initial capital cost that remains "unused" by 2030. This is then considered as an income in 2030 for the NPV equation. For a measure with cost C and lifespan L that has a lifespan beyond 2030, its terminal value TV is given by the equation:

$$TV = C \times (\text{Lifespan remaining beyond 2030} / L)$$

where lifespans are measured in years.

5.10.5 Shadow Price of Carbon

The financial assessment of stock refurbishment outlined above does not take into account the benefits to society as a whole of achieving carbon emission reductions. This issue can be addressed by putting a notional financial value on each tonne of carbon dioxide saved. This was done in the present research using Defra's Shadow Price of Carbon (SPC) (Defra 2007f). The SPC is a measure of the marginal damage caused by the emission of an extra tonne of carbon dioxide, and the UK Government recommends that it is used for any public sector financial appraisal.

Defra give a 2007 value for the SPC of £25, and recommend that it is increased by 2% a year in real terms beyond that date (Defra 2007f). There is some debate amongst academics and economists whether this is an appropriate figure to use, and figures ranging from $25 to $85 dollars per tonne of carbon (equating to a range of £23 to £77 per tonne of CO_2 in 2011) have been suggested (Tol 2005).

Where the SPC is employed, the difference in annual total emissions for each year from 2011 to 2030 for each considered refurbishment approach relative to the Base approach is calculated. These figures are then converted into a monetary value using the values for the SPC provided by Defra, providing an additional cash flow in each year for the NPV analysis. Applying the SPC figure has the effect of increasing NPV for each refurbishment approach, as the annual carbon emissions savings for each year up to 2030 relative to the Base approach are multiplied by the SPC, to create a notional increase in income. The high and low possible figures for the SPC given by Tol (2005) were used to conduct sensitivity analysis to generate upper and lower estimates of its impact.

5.11 Costs for Residents

Average annual fuel costs for each estate are calculated using model outputs on fuel use and assumed fuel costs given in section 5.8. Average costs for the whole stock are calculated by taking an average across all Peabody dwellings. Fuel poverty levels are also estimated for each estate and the stock as a whole, with the method used to do this given in section 5.11.1.

5.11.1 Estimating fuel poverty levels

A household is defined by the UK government as being in fuel poverty if it needs to spend 10% of its total income on fuel to provide an adequate level of energy service (Defra 2004a). Fuel bill expenditure and the range of incomes and household sizes found on Peabody estates were used to calculate genuine estimates of fuel poverty levels using this definition. This differs from a common approach of focussing on dwellings alone and assuming a low household income in each case (such as for a single pensioner (Newark and Sherwood Energy Agency 2005; Wilkinson 2007) or a single adult on benefits (ACE 2005b). The latter approach can be used to identify if all dwellings studied are “fuel poverty proof”, but for this research, the fuel poverty levels across Peabody stock were of greater interest.

Modelling fuel poverty levels was challenging, as the variables under consideration (income levels and fuel spending) vary significantly in real life around any average figures on Peabody estates. A statistical approach similar to the BBN method discussed in 5.1 could have been utilised to take this into account, using probability density functions to describe the variation in each variable for each estate. This was not possible with the spreadsheet software used for the PEM study, so a relatively simple method was developed which addressed these issues as much as possible.

As total household incomes are of interest, the method developed assumed that only adult householders contribute an income in each dwelling, and therefore calculated average fuel costs per adult householder. Based upon Peabody resident data on the age composition of its households (CORE 2006), the number of adults per household, A, was estimated based upon the number of residents, N, using a linear equation which fitted well with the available data:

$$A = 1 + (N-1) \times 0.35$$

It was assumed that adults in Peabody homes have an income ranging between the minimum and maximum figures given in Table 5.25 (based upon Peabody resident data), with the distribution skewed towards the minimum level. Incomes are not assumed to increase beyond the rate of inflation during the period considered in the model, so the figures in Table 5.25 are used for each year where fuel poverty is assessed.

Minimum Income	Maximum Income	Min. fuel poverty threshold	Max. fuel poverty threshold
£7069	£20800	£707	£2080

Table 5.25 Minimum and maximum incomes used for fuel poverty calculations

A starting assumption was that if average fuel costs were calculated as being below 10% of the minimum income level, no households were assumed to be in fuel poverty. Conversely if average fuel costs exceeded 10% of the maximum income, all households were assumed to be in fuel poverty. For average fuel costs between these levels, the statistical package SPSS was used to generate a function to join these start and end points, using an inverse function to take into account the relatively high number of households on lower incomes.

This initial approach was then refined due to its tendency to underestimate fuel poverty levels where fuel bills are relatively low. For example, where average fuel costs per adult resident are estimated as £700 (a short way below the minimum fuel poverty threshold), the method as described above would conclude that no householders are in fuel poverty. This would be inaccurate as the average figure for fuel costs would hide significant variation between households, including some households with significantly higher fuel spending.

To take account of this variation, it was therefore assumed that the spread of fuel costs making up the average for a Peabody estate made up a normal distribution. To capture this assumption simply so that it could be incorporated in the model, the assumed distribution was split into five parts using the 3-sigma rule (which states that 99.7% of a normal distribution lies within three standard deviations of the mean, with standard deviation signified as "σ" (sigma)). A standard deviation of one third of the mean was assumed so that the range of the approximated distribution goes from zero to twice the mean in each case. This gives a range of energy use that is representative of that found where energy use was monitored on Peabody's BedZED estate (Bioregional 2008).

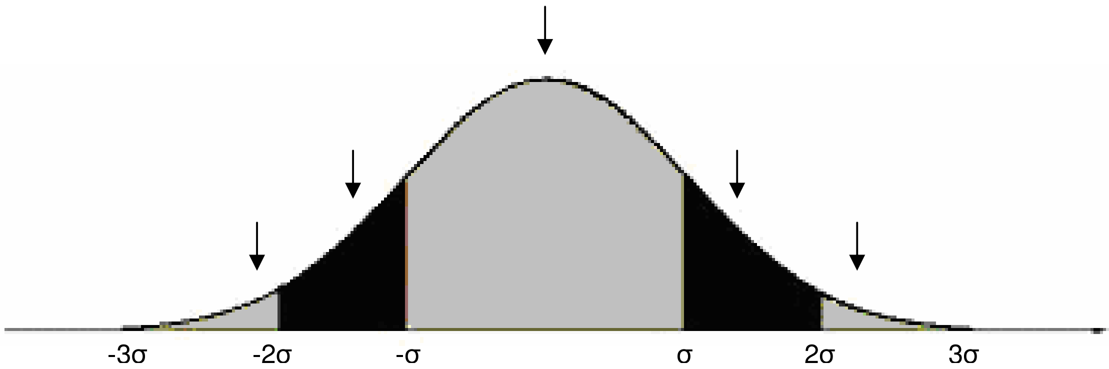

Figure 5.9 Illustration of approximation of normal distribution

Five points are then considered for average fuel prices instead of just one average fuel price, with their values and weights relative to the average fuel price C given in Table 5.26, and their position on the normal curve illustrated in Figure 5.9 (the weights represent the shaded areas as a fraction of the area under the curve).

Weight	Value for fuel costs
0.68	C
0.14	C*1.45
0.14	C*0.55
0.02	C*1.75
0.02	C*0.25

Table 5.26 Five values used to approximate range of fuel costs

The rule described above for estimating fuel poverty based upon average fuel costs was then applied to each estate from 2006 to 2030 for each of the five values derived from the average value C. This provided an improved estimate of fuel poverty that takes some account of the spread of expenditure on fuel around the average. The resultant relationship between fuel costs per adult resident and households in fuel poverty is shown in Figure 5.10.

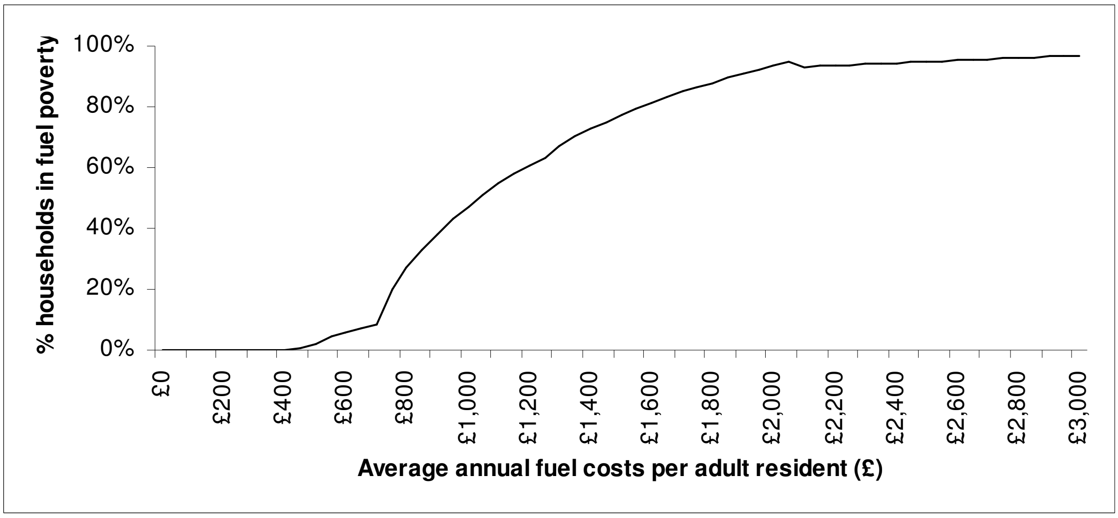

Figure 5.10 Relationship between fuel costs per adult and fuel poverty levels

5.12 Sensitivity analysis

Sensitivity analysis was undertaken to explore the validity of findings from the PEM study, by identifying the impacts of changing variables on four key model outputs: carbon emissions (measured as the % reduction to 2025); NPV; Peabody NPV; fuel poverty levels in 2030. The results are intended to reveal both the most significant variables, which have the greatest influence on results if changed, and the robustness of the results, by identifying whether the model outputs are significantly altered by changes in variables. This section describes the two methods used for sensitivity analysis: changing model variables to take into account uncertainty about their values (5.12.1) and changing variables to identify the value necessary for a desired result (e.g. achieving zero NPV) to be achieved (5.12.2).

5.12.1 Methods for investigating uncertainty

The impact of changes in values of model variables was identified for each approach in each scenario. For each variable, a high and low alternative value was considered, chosen to represent the likely range of uncertainty of the value in question. All model variables for which there was potential uncertainty over an appropriate value, or for which the appropriate value could potentially change over time were considered. This led to 11 scenario-specific variables and 47 other variables being studied.

For each variable considered a maximum and minimum value were used for the analysis, either based upon judgement of the appropriate range of values identified in reviewed literature or through Peabody experience where possible, or using a range of ±10% where there was a good degree of confidence about its value. This resulted in a range of uncertainty for values of between ±10% and ±50%. The latter assumption was used where uncertainty was felt to be significant, such as for the installation costs for CHP systems. A summary of the values used is given in Appendix I.

In some cases, an assumption in the model could not be increased or decreased, where it was already at a theoretical limit. In a very small number of cases, the structure of the model made it impractical to make changes for particular variables, although in each case, it was checked that these assumptions did not significantly affect results if changed.

5.12.2 Method used for meeting desired targets

As a result of sensitivity analysis, a number of key variables were identified which could vary significantly and, if changed, could substantially affect the model results (chapter 6). For each variable, the value(s) required to give a desired result were calculated for each scenario and refurbishment approach using the “goalseek” function in Microsoft Excel for four model outputs: CO_2 emission reductions to 2025; NPV; Peabody NPV; fuel poverty levels in 2030. The desired results used for each output were respectively: 57.4% emission reductions (a target derived in 5.13); zero NPV; zero Peabody NPV; no households in fuel poverty.

The variables explored in this way were: resident demand for energy; carbon intensity of grid electricity; discount rate; grant funding; fuel costs; refurbishment costs; refurbishment costs for alternatives to the Base approach. The methods used for each are given in Table 5.27.

Variable	Method
Refurbishment costs	All costs were multiplied by some constant (with an original value of 1, giving no change in the original assumed costs), and the value (if any) of this constant that allowed a zero NPV or Peabody NPV to be achieved was calculated.
Refurbishment costs for alternatives	As above, but only applied to measures that are used to a greater extent in refurbishment approaches that go beyond the Base approach.
Carbon intensity of grid electricity	The originally assumed annual change from 2011 was assumed to either increase or decrease by some constant value, and the value required to achieve a 57.4% emission reduction was calculated. The result of this was then reported as the value for grid intensity in 2025, rather than the revised annual increase/reduction in grid intensity up to that period.
Fuel costs	It was assumed for simplicity that the annual percentage changes in prices from 2008 are the same for gas and electricity. The values that led to a zero NPV and the values that led to a zero Peabody NPV were then calculated (if they existed).
Resident energy demand	It was assumed for simplicity that demand for each type of energy service (heat, hot water, etc.) changed to the same degree, so that a level of change that led to the GLA's 2025 target being met could be identified. Demand for each use and each year was increased/decreased annually by the same percentage, so that the value that led to exactly 57.4% reductions being achieved by 2025 could be calculated. The results are presented as the percentage change in demand by 2025.
Discount rate	For the discount rate assumption, calculating an alternative value that led to a zero NPV or a zero Peabody NPV was straightforward, as only one input variable for the model needed to be changed.
Grant funding	An equal percentage of grant funding for capital costs for insulation and micro-generation measures is assumed. It is also assumed that this percentage of estates are refurbished at no cost to Peabody through “Low Carbon Zones” funding.

Table 5.27 Methods used for changing key model variables

5.13 Carbon reduction targets

As outlined in chapter 2, progress on CO_2 emission reduction was measured against two targets: the target set by the GLA for 2025 in the London Climate Change Action Plan; and the longer term aspiration of achieving zero net CO_2 emissions by 2030. This section reports the methods used for applying these targets to Peabody stock.

5.13.1 GLA target

The London Climate Change Action Plan aims to reduce carbon emissions in London by 60% by 2025 (excluding emissions from aviation), based on a 1990 baseline. For housing, the report states that total emissions in 2006 are 16.7 Mt of CO_2, and that the targets for 2016 and 2025 are 12Mt CO_2 and 7.5 Mt CO_2 respectively. As a percentage reduction relative to the 2006 baseline, this target represents a reduction of 55% to 2025. However, the total emission figures refer to all housing in London, and as it is planned that additional housing will be constructed in the city in the period up to 2025, some of these emissions will come from new housing. As a result, the emission reduction targets for existing housing need to be greater than this 55% figure.

Calculating the emission reduction targets for existing housing requires assumptions on the emissions from new homes constructed in London after 2006. It was assumed for this research that, following projections in the London Plan, 30,500 additional homes are constructed in London every year to 2016 (GLA 2004). Average emissions from a new home are assumed to decline linearly from 2007 new build levels of 4.1 tonnes per annum (Stepping Forward 2007) to zero by 2016, based upon the assumption that new homes built from that date produce zero net carbon emissions (CLG 2007b). Assuming that emissions from each new dwelling do not change to 2016 (so, for example, a home built in 2007 produces 4.1 tonnes of CO_2 each year to 2016), the total emissions from new homes in 2016 is 0.625 Mt of CO_2. By 2025, it is assumed that total emissions from these new homes are at 62.5% of emissions in 2016, in line with the planned reduction in total emissions from London housing between those dates (a reduction from 12Mt to 7.5Mt per annum). This gives emissions of 0.39 Mt in 2025 from new homes, and total target emissions for existing housing of 7.5Mt minus 0.39 Mt, giving 7.11 Mt. This gives a target percentage reduction in emissions relative to 2006 levels by 2025 of 57.4%.

As a result, through consideration of homes built in London after 2006, target reductions for 2025 for existing homes in London are increased from 55% to 57.4%. If house building rates do not match those assumed for the London plan, as may be the case given the downturn in construction activity at the time of writing, this would have the effect of reducing the emission reduction target for existing housing from 57.4% towards the 55% target that would apply if no new homes were constructed.

It is assumed that the reductions in emissions required for Peabody stock relative to a 2006 baseline are equivalent to those required for existing housing in London. This decision was taken as it is the simplest and most intuitive application of the target. Some issues affecting the appropriateness of this judgement are discussed in the light of this study's results in section 9.1.1.

5.13.2 Zero-carbon target

The definition of zero carbon housing has to date largely been addressed in the UK in the context of new build housing (CLG 2007b; UKGBC 2008b). The definition originally put forward by the UK Government was that a development is zero-carbon if the net carbon emissions on-site are zero or less (CLG 2007b). Net carbon emissions are any emissions caused by on-site energy use minus any emissions offset due to on-site energy generation (ibid). This onsite-only definition was challenged by the UK Green Building Council

(UKGBC 2008b), which suggested that offsite generation could be permitted if it was demonstrated to provide genuinely additional renewables capacity, and that emissions could be offset by paying into a carbon trading scheme or Community Energy Fund. The recently revised Government definition broadly supports this approach, defining zero-carbon homes as having “high energy efficiency, on- or near-site carbon reduction” and using “allowable solutions” to deal with any remaining emissions (CLG 2008c).

For this research, the former approach of defining zero-carbon homes in terms of achieving zero net carbon emissions has been used. This captures the aim of assessment against a zero-carbon target by assessing the limits of what can be achieved on the level of Peabody estates, without recourse to external offsetting of emissions.

5.14 Summary

This chapter has reported the methods used to develop the Peabody Energy Model, which has been used to quantitatively analyse interventions to reduce carbon emissions on Peabody estates. The results generated by the model are reported in chapters 6 and 7. Chapter 6 reports findings relating to the four original refurbishment approaches considered. Chapter 7 reports the impacts of the particular measures studied, explores the effects of changing constraints affecting refurbishment and reports possible strategies for meeting carbon reduction targets.

Chapter 6: Initial model results

Results from the Peabody Energy Model (PEM) study are presented across two chapters. The present chapter puts forward the broad-level findings of the study, whilst chapter 7 provides further analysis of the results, including descriptions of approaches for meeting carbon reduction targets. Results are presented in this chapter for the three main issues considered: carbon emissions (6.1), resident fuel costs (6.2), the financial impacts of refurbishment (6.3). For each issue considered, model outputs are presented alongside results from sensitivity analysis, to help identify the robustness of conclusions. The main findings are summarised in section 6.4.

Results are presented either for Peabody stock as a whole, or Peabody stock divided up into five categories of dwelling. This categorisation is carried out to highlight the impact that dwelling type has on the issues considered and to provide evidence to support generalisation from Peabody's case to that of housing providers with differing stock profiles. The five categories considered are: Electric; Scattered; Modern; Recent; Old. *Electric* estates are those having mostly (or entirely) electric heating. All but one of these estates were built in the last 20 years. *Scattered* estates consist of street properties with a greatly varying age profile. The remaining estates were divided up according to their date of construction: *Modern* estates are those built after 1991; *Recent* estates are those built between 1951 and 1991; *Old* estates are those built before 1951, and are typically solid-walled blocks of flats.

A more extensive discussion of results than is possible in the present thesis was presented in the report "Towards a Low Carbon Peabody" (Reeves 2009). Findings from that report are referred to in both the present chapter and in chapter 7 to supplement those findings presented in this thesis.

6.1 Carbon Emissions

6.1.1 Baseline emissions

Average emissions per resident for Peabody stock for the baseline year 2006 broken up by stock type are shown in Figure 6.1. Current UK average annual emissions per resident of

2.6 tonnes (based upon average household emissions of 6.1 tonnes and average household size of 2.3 (Defra 2007g)) are displayed for comparison.

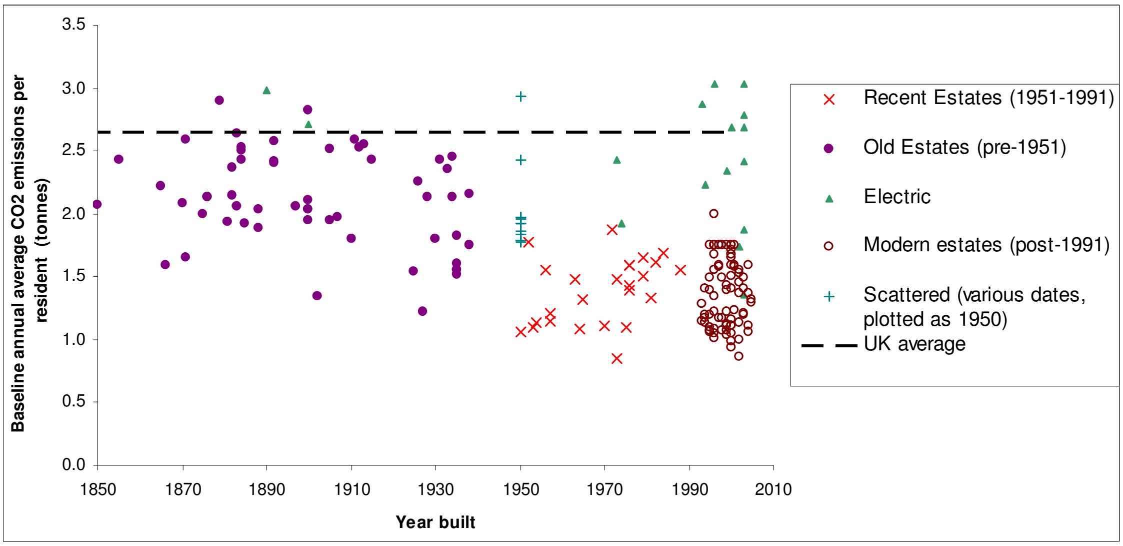

Figure 6.1 Baseline CO2 emissions per resident by estate

The results indicate a clear trend of average emissions per resident declining the more recently an estate was built. Emissions on electrically-heated estates are comparatively high, despite their relatively modern construction, due to the higher emissions associated with using electricity for heating. Emissions per resident on each estate are typically below the UK average. This is also the case for emissions on a per dwelling basis, with Peabody stock averaging 3.6 tonnes of CO_2 per dwelling per annum. This is largely due to Peabody homes being smaller than average (with an estimated average floor area of 57m^2) and having lower occupancy (2.0 residents per home, compared to 2.3 in the UK (Defra 2007g)). Domestic emissions per resident in London are approximately 8% lower than the UK average (based upon Defra (2007h)). With average emissions per resident of 1.8 tonnes per annum, 32% below the UK average, Peabody stock emissions are therefore also below the London average.

6.1.2 Emission Reductions

The emission reductions achieved by 2025 for each refurbishment approach under the four considered scenarios (“Keeping the Lights On”, “Sustainable Development”, “Power Down” and “Breaking Down”) are shown in Table 6.1.

	KLO		SD		PD		BD	
	2025	2030	2025	2030	2025	2030	2025	2030
Base	-19%	-21%	-41%	-46%	-46%	-53%	-30%	-37%
Fabric	-33%	-36%	-52%	-57%	-56%	-63%	-43%	-49%
Communal	-35%	-37%	-56%	-60%	-60%	-66%	-44%	-51%
Renewables	-42%	-44%	-63%	-66%	-67%	-71%	-51%	-58%

Table 6.1 Emission reductions to 2025 and 2030

Each approach in each scenario leads to reductions in emissions. For the Base approach, this is due to the assumed decline in carbon intensity of the grid, and to the gradual replacement of existing boilers with more efficient models. Assumed reduced demand for energy in the BD scenario (relative to KLO) and PD (relative to SD) leads to deeper emissions cuts.

Fabric improvements lead to emission levels at least 10% below those of the Base approach. Their impact is greatest in scenarios where demand for heat is assumed to be higher. Communal heating installations have a relatively low overall impact, providing a further cut beyond the Fabric approach of up to 3% by 2030. They are most effective in the SD and PD scenarios, due to assumptions of greater availability of district heating and the availability of lower-carbon district heating fuels. Solar PV and solar thermal provide further cuts of between 5% and 7% by 2030. The maximum cut in emissions achieved by 2030 is the 71% reduction resulting from the Renewables approach in the PD scenario.

6.1.2.1 GLA 2025 target

The key result regarding the 2025 target is that it can only be achieved in the two scenarios defined by strong action on climate change (Figure 6.2). For the KLO and BD scenarios, even the most extensive approach to refurbishment considered is insufficient to meet the GLA carbon reduction target.

In both scenarios where the target is achieved, Peabody's current planned approach to refurbishment (the Base approach) is not sufficient to bring this about. For the SD scenario, only the Renewables approach is sufficient. The PD scenario, which has greater assumed reductions in energy demand, can achieve the target through the Communal or Renewables approaches, and is close to doing so through fabric improvements alone.

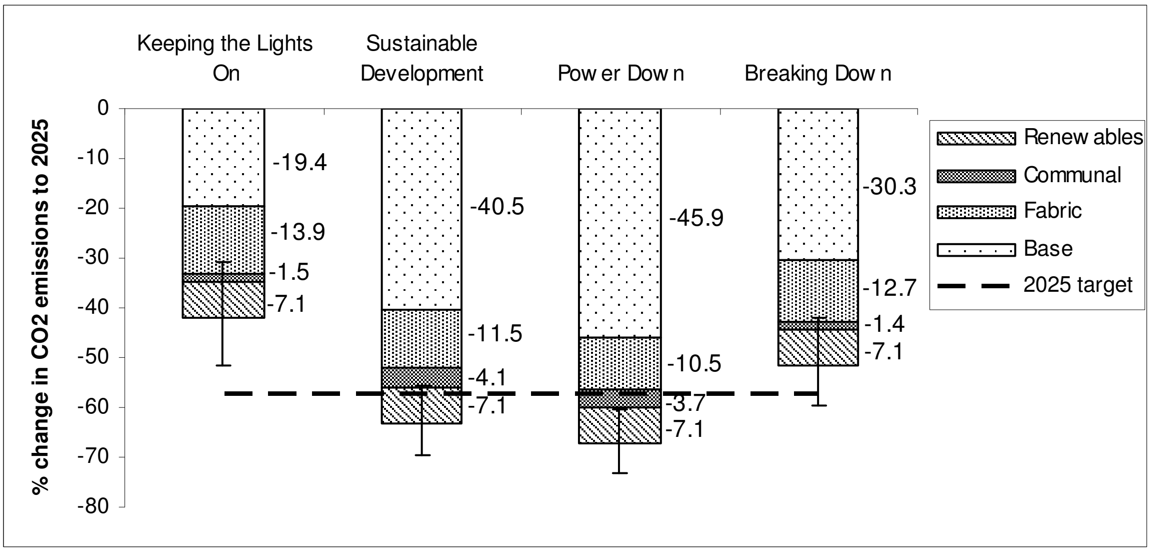

Figure 6.2 Emission reductions to 2025 by scenario

The error bars on Figure 6.2 indicate the results of the sensitivity analysis on the model outputs for the Renewables approach (described in 6.1.3 below), illustrating the maximum and minimum reductions achieved where model variables are changed to reflect uncertainty in their values. By taking into account the impact of this uncertainty, it is suggested here that the target can be met with a *good degree of confidence* for a particular scenario if it is met even for the lower limit on emission reductions identified through the sensitivity analysis. By this definition, only the Renewables approach in the PD scenario can be said to allow the 2025 target to be met with a good degree of confidence.

6.1.2.2 Reductions by stock type

Emission reductions achieved vary according to the type of stock treated. The broad trends found in all scenarios are illustrated in Table 6.2 by an approach that meets the 2025 target with a good degree of confidence in the PD scenario (described in section 7.3).

Stock Type (and % of stock)	2006 emissions per home per annum (tonnes)	2006 annual emissions per resident (tonnes)	Emission reductions to 2025 (PD scenario)	2025 annual emissions per resident (tonnes)
Modern (14%)	2.5	1.4	48%	0.7
Recent (14%)	2.8	1.4	57%	0.6
Old (51%)	3.7	2.2	74%	0.6
Electric (3%)	4.0	2.4	70%	0.7
Scattered (18%)	4.8	2.0	63%	0.7
Peabody Average	3.6	1.8	67%	0.6
UK Average	6.1	2.7	N/A	N/A

Table 6.2 Emissions and emission reductions by stock type

Prior to refurbishment, emission levels per resident vary significantly between estate types, although all are below the UK average. After refurbishment, they are very similar, between 0.6 and 0.7 tonnes per annum. The greatest percentage reductions are achieved on older estates and estates with electric heating — those which currently have higher emissions and the greatest potential for reductions. These high reduction levels offset the relatively low reductions on modern estates, enabling the GLA target to be met overall.

6.1.3 Sensitivity analysis

6.1.3.1 Most significant variables

The tornado charts (Figures 6.3 and 6.4) illustrate the effect of changing particular model variables for two of the four scenarios considered for the Renewables approach. The full list of variables considered and the changes in variables explored is shown in Appendix I. The Renewables approach was chosen as all possible refurbishment measures are applied, so any significant impacts of changing variables can be observed. The results displayed are just those that change the emission reduction results by at least 1%.

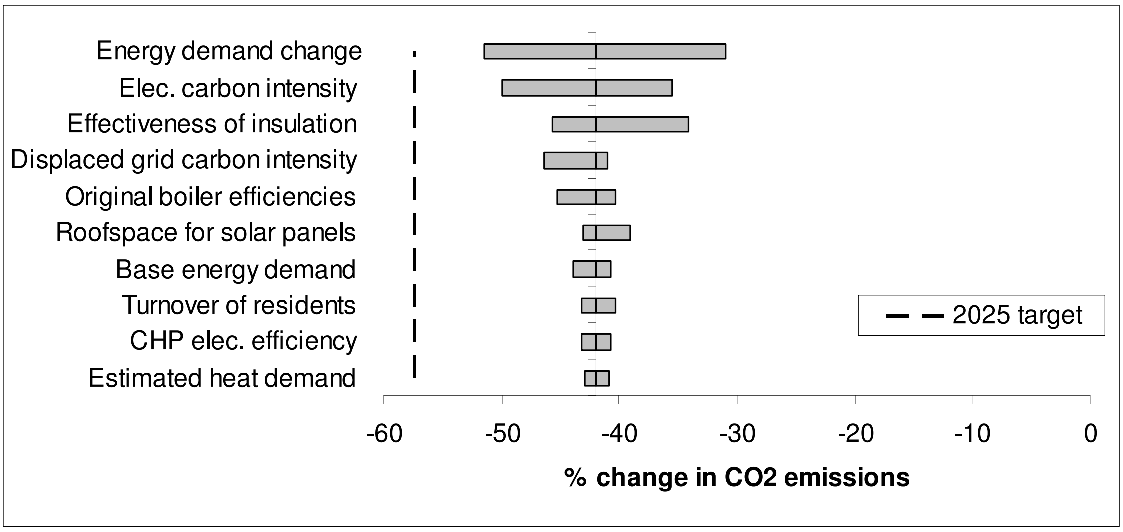

Figure 6.3 KLO Renewables sensitivity analysis for carbon emissions

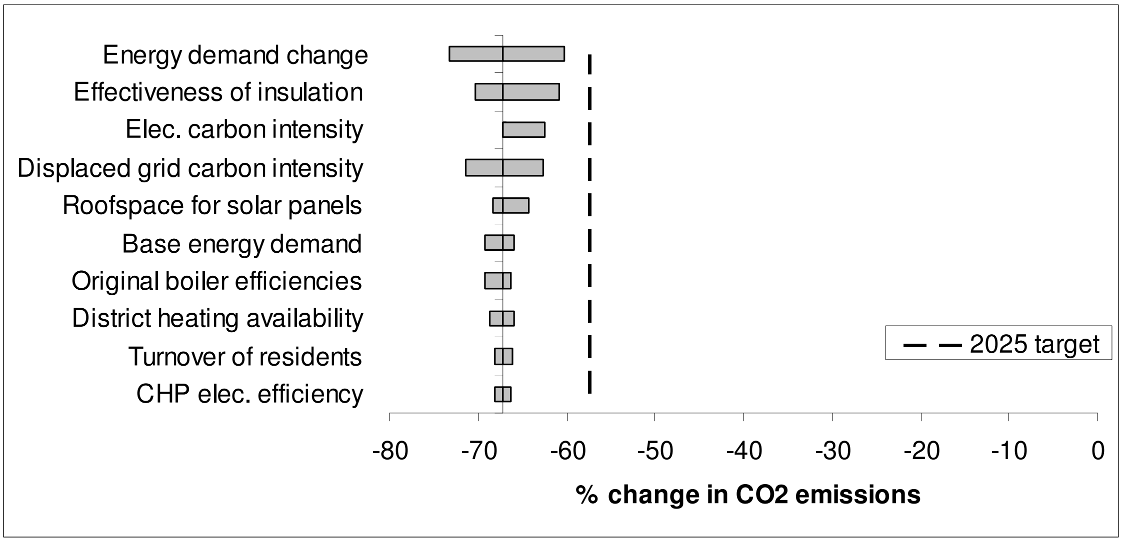

Figure 6.4 PD Renewables sensitivity analysis for carbon emissions

For all four scenarios, the assumed change in energy demand is the most significant variable, followed either by the assumed carbon intensity of electricity or the assumed effectiveness of insulation at reducing heat demand. The assumed carbon intensity associated with displaced grid electricity also has a significant impact. Of the four most significant variables identified, two therefore relate to external contextual factors used to define scenarios (energy demand and carbon intensity of electricity) and two relate to uncertainties about the most appropriate model assumptions.

Other assumptions have a relatively low impact on results, indicating that the model results appear to be robust even if these assumptions are changed. This includes a number of assumptions for which there was some uncertainty, such as average floor areas, average window areas or estimated heat demand per square metre.

6.1.3.2 Meeting the 2025 target

For each scenario and approach, the maximum and minimum emission reductions achieved after changes of variables were compared to the reductions achieved using the original model assumptions. The results of this are shown in Figure 6.5, using error bars to illustrate the maximum and minimum results in each case.

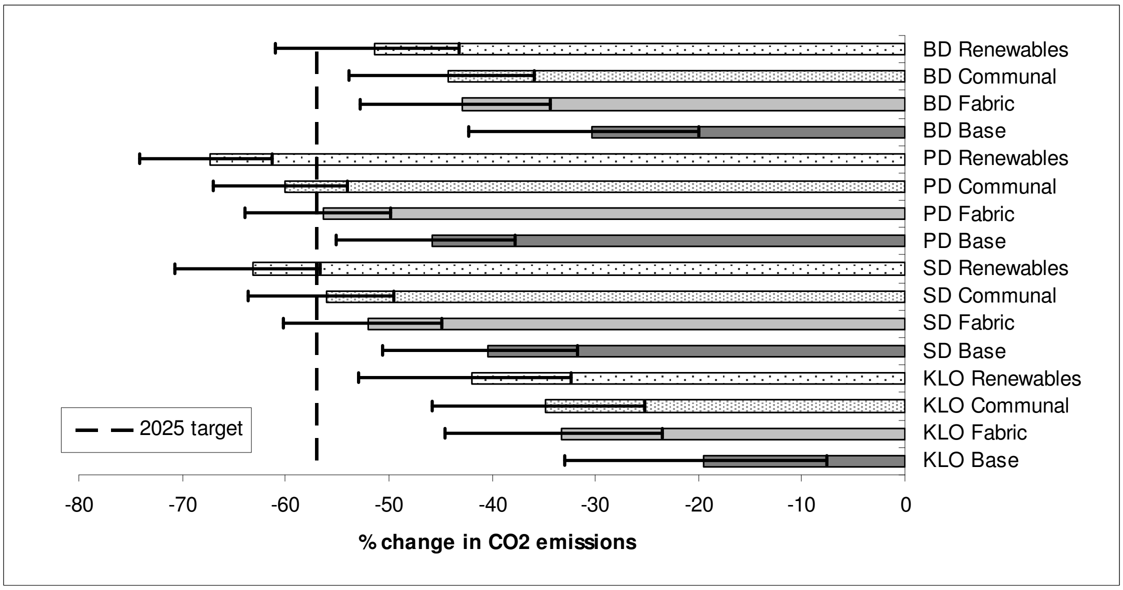

Figure 6.5 Sensitivity analysis for carbon emissions

With outputs differing by up to 13%, this analysis indicates significant uncertainty in the model results. As a result, the outputs can usefully be considered in probabilistic terms. For example, if an approach leads to emission reductions that exactly achieve the 2025 target, this could be interpreted as indicating a 50:50 chance that the 2025 target is met (assuming it is equally likely that reductions above or below the target are achieved in practice). It follows that the greater the difference between calculated emission reductions and the 2025 target, the greater the confidence that the conclusion (of the target being met or missed) is accurate. A “good degree of confidence” of the target being met was put forward above as a means of taking this uncertainty into account, whilst also making it possible to define actions that are likely to successfully meet the 2025 target.

Despite the uncertainty associated with the results, the Base approach seems very unlikely to allow the 2025 target to be achieved in any scenario. More extensive approaches are shown to have some chance of success with the likelihood depending largely on scenario-specific assumptions such as energy demand levels.

6.1.3.3 Values required to meet the 2025 target

Two key contextual variables were identified through the above analysis: changes in energy demand from residents and the carbon intensity of grid electricity. For each variable, the values required to exactly allow the 2025 carbon reduction target to be met were calculated. This was done for each scenario, assuming that all other assumptions for the scenario in question remain unchanged.

Changes in energy demand are considered by changing demand levels for heating, electricity, etc to an equal extent relative to the base year (see table 5.2.7). The results for resident energy demand (Table 6.3) indicate a range of +1% to -41%, with the greatest demand reductions required where there is a less extensive refurbishment approach.

Approach	Keeping the Lights On	Sustainable Development	Power Down	Breaking Down
Base	-41%	-35%	-35%	-41%
Fabric	-28%	-20%	-20%	-28%
Communal	-26%	-13%	-13%	-26%
Renewables	-15%	+1%[1]	+1%[1]	-15%

Table 6.3 Resident energy demand changes to meet the 2025 target

The results for carbon intensity of grid electricity (Table 6.4) demonstrate a significant difference between scenarios and approaches. The Base approach is insufficient in each scenario except Power Down, where grid electricity needs to be almost entirely zero-carbon. The combination of the Fabric approach and a near to zero-carbon grid is the only way for the target to be met in the KLO scenario. The Communal and Renewables approaches cannot meet the zero-carbon target in the KLO scenario, because where grid carbon intensity is very low, the Communal approach leads to an increase in emissions, and the impact of the Renewables approach is greatly decreased.

Approach	Keeping the Lights On ($kgCO_2/kWh$)	Sustainable Development ($kgCO_2/kWh$)	Power Down ($kgCO_2/kWh$)	Breaking Down ($kgCO_2/kWh$)
Base	N/A	N/A	0.016	N/A
Fabric	0.027	0.141	0.233	0.101
Communal	N/A	0.230	0.323	0.003
Renewables	N/A	0.381	0.764	0.262

Table 6.4 Carbon intensity of grid electricity in 2025 to meet the GLA target

The results demonstrate potential for the GLA target to be achieved if substantial reductions in the carbon intensity of the grid are achieved. For example, a 56% reduction (giving a grid intensity of 0.23) would make both the Communal approach in SD and the Fabric approach in PD successful.

[1] This result indicates that the target can be met with no reduction in energy demand.

6.2 Resident fuel costs

6.2.1 Baseline costs

Due to recent increases in fuel costs, baseline costs are shown for 2008, not 2006. Fuel costs per resident in 2008 follow a similar trend to CO_2 emissions, being greater in older Peabody stock (due to greater needs for space heating and less-efficient heating systems), and greater on electrically-heated estates, due to the relatively high cost of energy from electricity (Figure 6.6).

Average annual UK fuel costs of £573 per householder are shown for comparison (based upon average costs of £1317 per dwelling with British Gas standard tariffs (BBC News 2008), and assuming 2.3 residents per home (Defra 2007g). Fuel costs are therefore below the UK average on all Peabody estates.

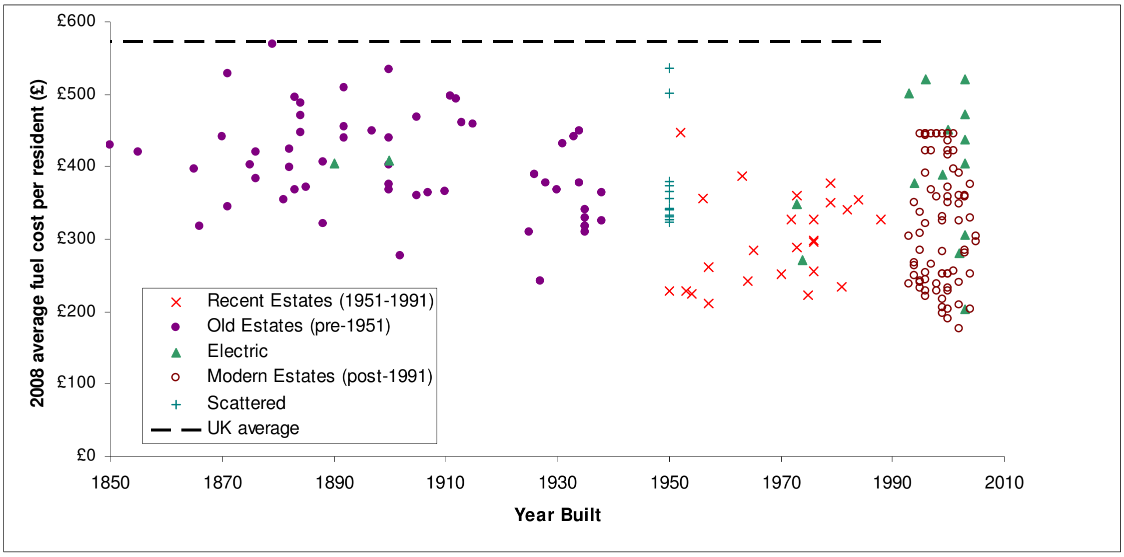

Figure 6.6 Baseline resident fuel costs by estate and stock type

6.2.2 Changes in costs

In 2030, average fuel costs have increased in real terms in each scenario (Figure 6.7). Fabric improvements lead to reduced costs relative to the Base approach, with this reduction ranging from £90 in the KLO scenario to £130 in the BD scenario. These reductions represent a relatively small part of total costs, indicating the strong influence of other energy use on fuel expenditure. The impact of communal measures is not shown in Figure 6.7 as it makes an insignificant difference to fuel costs. This is due to the assumption that energy is sold to residents at a price that leaves them no worse off than they would be if buying gas and electricity from utility companies (see 5.8.2). Solar PV installations also have no impact, as it is assumed that all electricity generated is exported. Solar thermal installations do however lead to a small further reduction.

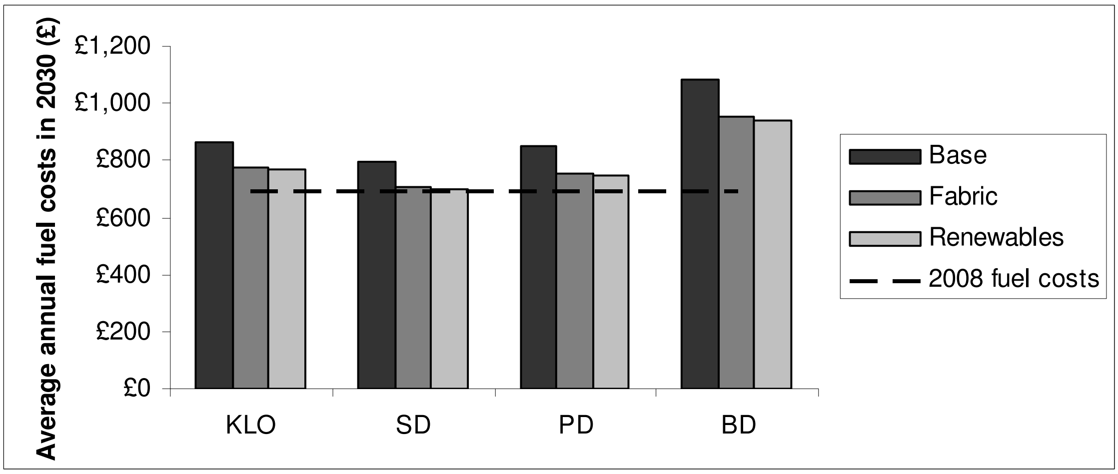

Figure 6.7 Average fuel costs in 2030 by scenario

The impact of fabric measures on 2030 fuel costs is demonstrated in Figure 6.8, using the SD scenario as a representative example. The results show that the gap in average fuel costs between older and more modern estates has been greatly reduced, and costs on electrically heated estates have been reduced through the installation of gas central heating.

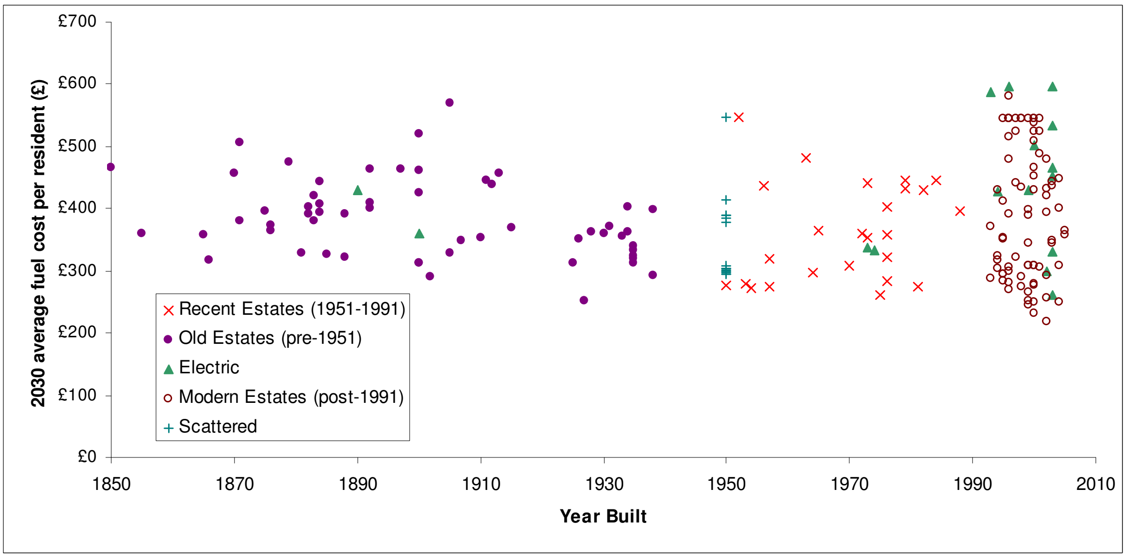

Figure 6.8 SD scenario, Fabric approach: average fuel costs per resident in 2030

6.2.3 *Fuel poverty*

Results are reported in this section for fuel poverty levels in 2008 and 2030. In chapter 7 the viability of eliminating fuel poverty by 2016 through a rapid programme of insulation improvements is also assessed.

6.2.3.1 Baseline results

In 2008, the PEM results indicate that Peabody estates have an average of 3% of households in fuel poverty. Considering the variation across stock types (Table 6.5) it is clear that baseline fuel poverty levels are very low in Recent and Modern estates, relatively high on Old and Electric estates and greatest on Scattered estates. The high fuel poverty levels on the latter estates are due to a high number of estates having uninsulated solid walls, and to many estates having large floor areas relative to the number of residents.

Classification	% households in fuel poverty
Recent Estates (1951 - 1991)	0.2%
Old Estates (pre-1951)	4.4%
Electric	2.2%
Modern Estates (post-1991)	0.2%
Scattered	4.4%

Table 6.5 Baseline fuel poverty levels by stock type

6.2.3.2 2030 results

By 2030, the assumption of increasing fuel prices in every scenario leads to increased fuel poverty levels wherever the Base approach is carried out (Figure 6.9). Fabric measures reduce fuel poverty levels by around 50% relative to the Base approach. This leads to fuel poverty levels similar to those in 2008 for all scenarios except BD.

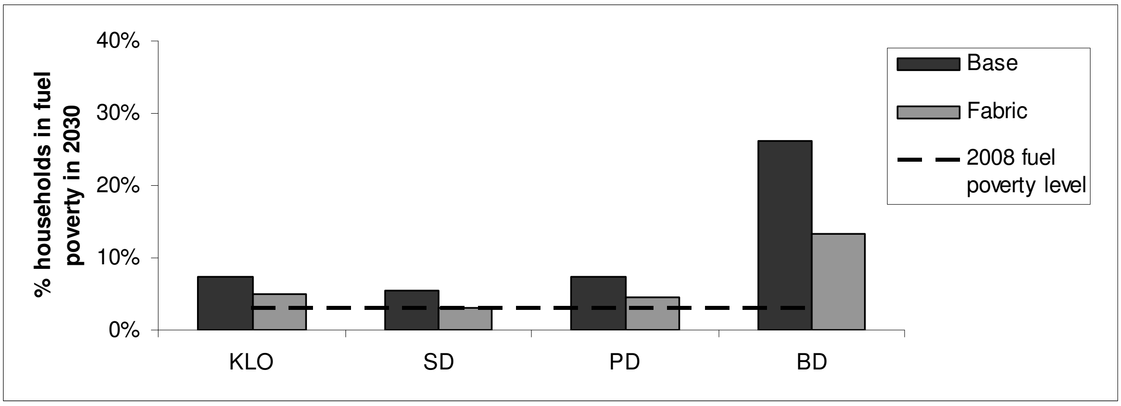

Figure 6.9 Fuel poverty levels in 2030

Fuel poverty levels in 2030 for different stock types are contrasted in Table 6.6 using the SD scenario, which is representative of the trends in all scenarios. Fabric improvements greatly reduce the significant range in fuel poverty levels between different stock types that were present in 2008.

Classification	% households in fuel poverty: Base approach	% households in fuel poverty: Fabric approach
Recent Estates (1951 - 1991)	2%	2%
Old Estates (pre-1951)	7%	3%
Electric	16%	4%
Modern Estates (post-1991)	2%	2%
Scattered	7%	4%

Table 6.6 SD scenario: 2030 fuel poverty levels by stock type

6.2.4 Sensitivity analysis

6.2.4.1 Most significant variables

The most significant variables affecting fuel poverty levels are the same for each scenario. The effects are illustrated here for the KLO and PD scenarios for all changes of variables that lead to a change in fuel poverty levels of more than 0.5% (Figures 6.10 and 6.11). In each case, as would be expected, changes in fuel prices and original fuel price assumptions have the greatest impact. Energy demand levels (original levels and subsequent changes) also have a significant effect. Some factors, such as changes in gas and electricity prices, are clearly not independent, so the total impact of these factors changing together would be greater than if they changed alone. The substantial range is due in part to the assumed low household incomes on Peabody estates, meaning that relatively small changes in fuel costs can create significant increases in fuel poverty levels.

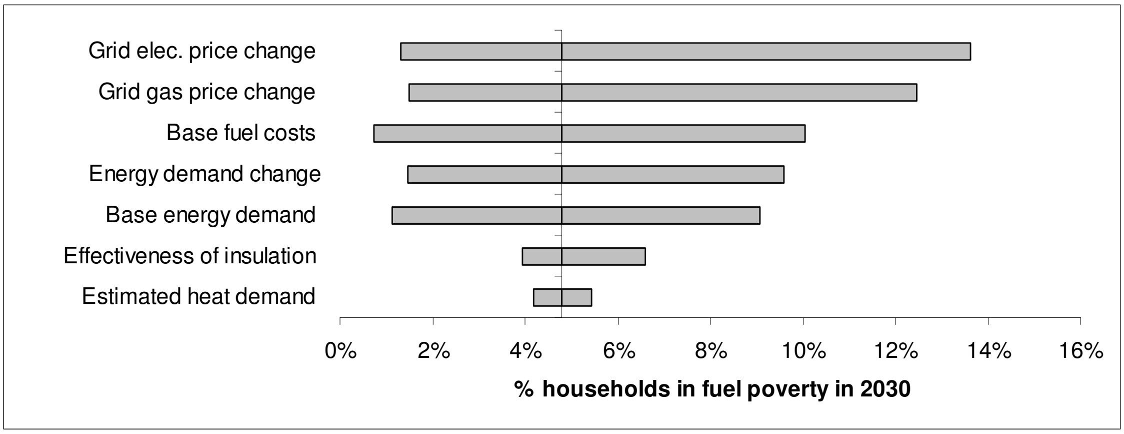

Figure 6.10 KLO Renewables sensitivity analysis for fuel poverty

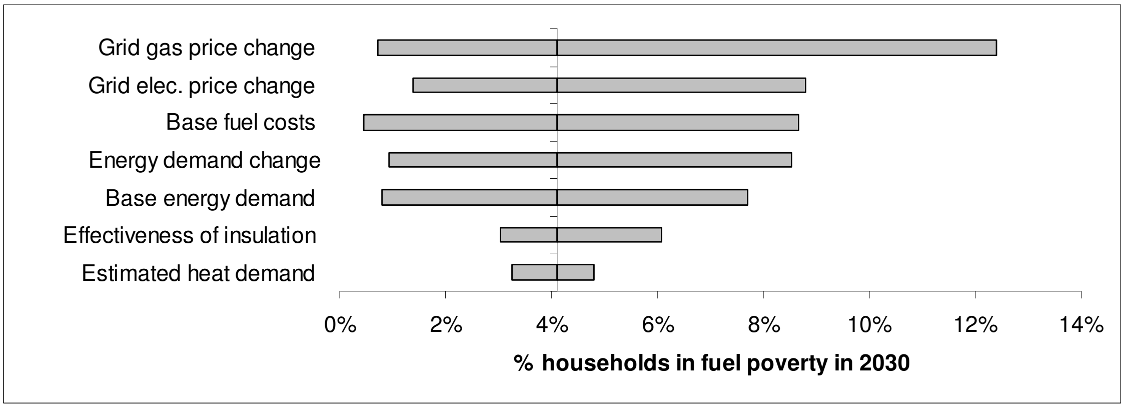

Figure 6.11 PD Renewables sensitivity analysis for fuel poverty

6.2.4.2 2030 fuel poverty levels

The results by refurbishment approach for 2030 indicate significant uncertainty in the model results for fuel poverty (Figure 6.12). The results reveal a risk that around half of Peabody households could be in fuel poverty if the high fuel prices of the BD scenario are combined with a lack of insulation improvements. For the lower fuel cost scenarios, the lower bound results of the analysis show that fabric improvements could lead to fuel poverty being virtually eliminated on Peabody estates.

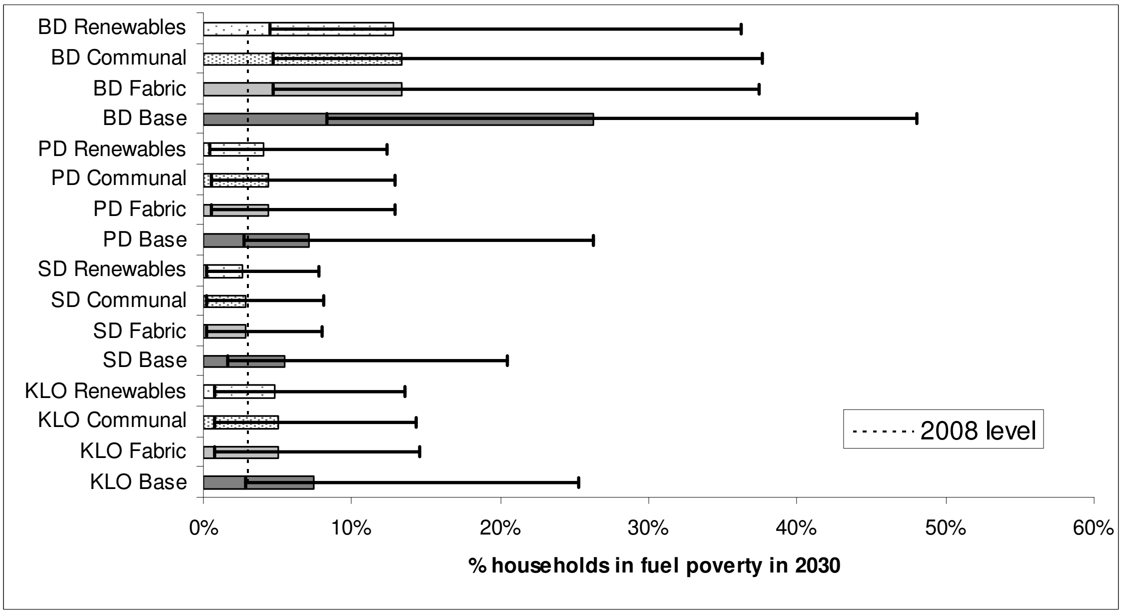

Figure 6.12 Sensitivity analysis for fuel poverty

6.2.4.3 Values required for zero fuel poverty

The analysis above identifies fuel costs and energy demand as the two key variables that significantly affect fuel poverty levels. For each approach and scenario, the values required for these variables to lead to the result of fuel poverty being eliminated on Peabody estates were calculated (Table 6.7). The "elimination" of fuel poverty is best interpreted here as fuel poverty levels being very close to zero, as given the great variance in average fuel costs between households, there are likely to be some households in fuel poverty even where average fuel costs are some way below 10% of average income levels.

For energy demand, challenging reductions relative to 2006 levels are required in each scenario, ranging from 20% in KLO to 56% in BD. The results for fuel costs indicate potential for fuel poverty to be eliminated on Peabody estates if fuel prices remain at comparable levels to the present day to 2030. The goal can be met even if fuel prices increase by up to 20% in the PD scenario, due to the assumed reduced energy demand. If fabric improvements are carried out, the maximum levels of both energy demand and fuel prices that can be associated with the elimination of fuel poverty are increased significantly.

	KLO	SD	PD	BD
Energy Demand: Base	-33%	-41%	-50%	-56%
Energy Demand: Fabric	-20%	-32%	-42%	-49%
Fuel Costs: Base	-31%	-20%	+0%	-18%
Fuel Costs: Fabric	-23%	+0%	+13%	+2%

Table 6.7 Energy demand and fuel cost changes required to eliminate fuel poverty

6.3 Financial impacts of refurbishment

The financial impacts of refurbishment are explored in a number of ways. Firstly, the net energy-related expenditure for Peabody up to 2030 is reported (6.3.1), followed by the capital costs for each refurbishment approach (6.3.2). A net present value (NPV) assessment of refurbishment approaches is then given, from two perspectives: Peabody considered alone ("Peabody NPV"); Peabody and its residents considered together ("NPV") (6.3.3.). Sensitivity analysis on NPV results is described (6.3.4), followed by an NPV assessment that puts a value on carbon emission savings using Defra's Shadow Price of Carbon to assess whether interventions are beneficial for society as a whole (6.3.5).

6.3.1 Net expenditure to 2030

Figures for net expenditure from 2011 to 2030 on energy-related equipment and services for each scenario are given in Table 6.8, taking into account all cash flows over that period.

For each refurbishment approach that goes beyond the base approach, net expenditure is increased. Costs are significantly greater in the KLO and BD scenarios, where there is less grant support assumed and lower reductions in installation costs for renewables.

	Keeping the Lights On	Sustainable Development	Power Down	Breaking Down
Base	£148m	£148m	£148m	£149m
Fabric	£215m	£195m	£191m	£214m
Communal	£232m	£212m	£204m	£230m
Renewables	£330m	£269m	£274m	£327m

Table 6.8 Net expenditure to 2030 by scenario

To illustrate the impact of refurbishment approaches on net expenditure, the breakdown of expenditure and income is shown below for the SD scenario (Figure 6.13 and Table 6.9). This breakdown indicates that for the Base approach, the vast majority of expenditure is on individual gas boilers. Over £110m is spent from 2011 to 2030 on their maintenance and replacement. Planned double-glazing installations over the considered period cost £31.1m, and expenditure on other servicing options (electric storage heaters, existing communal heating systems and gas cooker maintenance) contributes a further £5.6m.

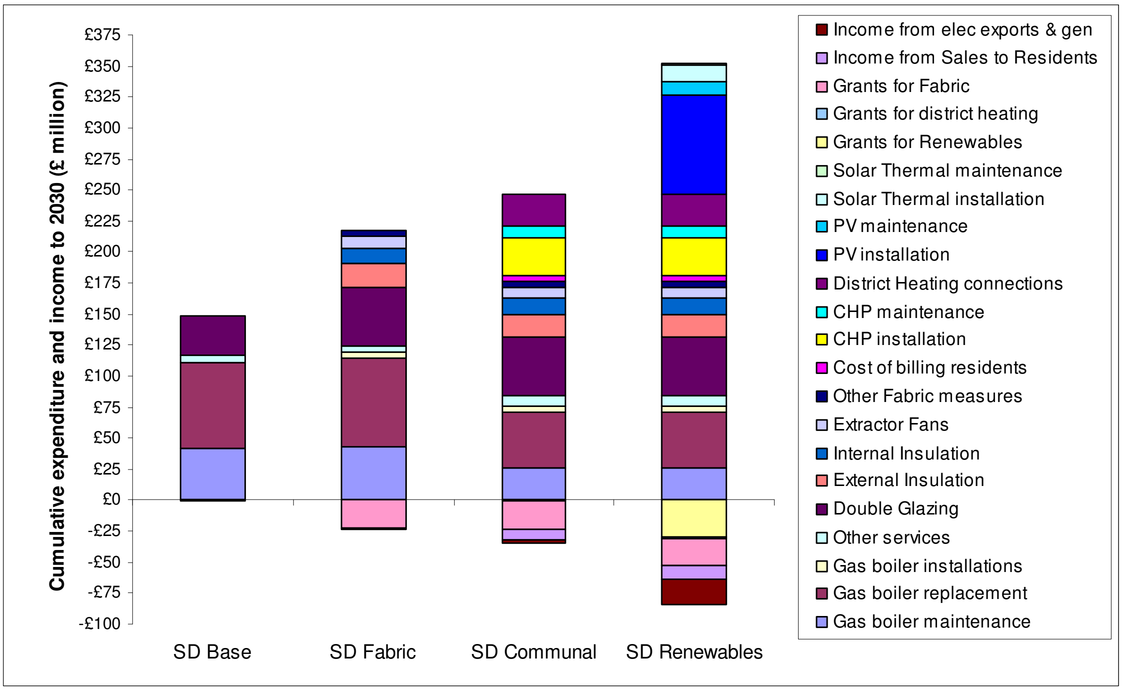

Figure 6.13 SD scenario: breakdown of Peabody costs

	Base	Fabric	Communal	Renewables
EXPENDITURE				
Gas boiler maintenance	£41,613,506	£43,097,839	£26,450,185	£26,450,185
Gas boiler replacement	£69,453,528	£71,930,900	£44,145,731	£44,145,731
Gas boiler installations	£0	£4,800,767	£4,800,767	£4,800,767
Other services	£5,646,018	£4,894,356	£8,455,045	£8,455,045
Double glazing	£31,113,825	£46,986,677	£46,986,677	£46,986,677
External insulation	£0	£18,844,376	£18,844,376	£18,844,376
Internal insulation	£0	£12,875,808	£12,875,808	£12,875,808
Extractor fans	£0	£9,249,184	£9,249,184	£9,249,184
Other fabric measures	£0	£4,214,700	£4,214,700	£4,214,700
Cost of billing residents	£0	£648,700	£4,499,508	£4,499,508
CHP installation	£0	£0	£31,315,992	£31,315,992
CHP maintenance	£0	£0	£9,730,698	£9,730,698
District heating connections	£0	£0	£24,800,250	£24,800,250
PV installation	£0	£0	£0	£80,230,778
PV maintenance	£212,148	£212,148	£212,148	£10,810,356
Solar Thermal installation	£0	£0	£0	£12,948,744
Solar Thermal maintenance	£0	£0	£0	£2,029,086
INCOME				
Grants for renewables	£0	£0	£0	-£29,400,431
Grants for district heating	£0	£0	-£1,053,530	-£1,053,530
Grants for fabric improvements	£0	-£22,487,005	-£22,487,005	-£22,487,005
Income from sales to residents	£608,642[1]	-£240,839	-£8,928,582	-£10,683,487
Income from electricity exports & generation	-£455,256	-£455,256	-£1,638,256	-£20,021,633
Total	£148,192,412	£194,572,355	£212,473,695	£268,741,798

Table 6.9 SD scenario: breakdown of Peabody costs

The extra expenditure for the Fabric approach is roughly equally split between: further double-glazing installations; external wall insulation; internal insulation measures; other fabric measures (primarily extractor fans). In the SD scenario a large fraction of this extra spending is grant-funded.

The Communal approach differs from the Fabric approach through significantly reduced spending on gas boiler maintenance and replacement. This saving is exceeded by spending on communal heating to replace individual gas boilers, with spending related to CHP installations making the greatest contribution. Despite an income being generated for Peabody through selling heat and electricity to residents, this is insufficient to offset the increased capital costs, so overall expenditure exceeds that of the Fabric approach.

[1] Peabody is making a loss by selling heat to residents in this case

The principal difference between the Renewables approach and the Communal approach is the considerable extra spending on PV installations. PV maintenance costs and costs associated with solar thermal have a relatively minor additional impact (Table 6.9). This spending is partially offset by income from exporting electricity to the grid, but still leads to a significant increase in net expenditure for Peabody.

6.3.2 Capital costs of refurbishment

There is little variation in capital costs for refurbishment across the four scenarios considered. The average costs from the four scenarios are shown in Table 6.10, both for those dwellings treated and the stock as a whole. These costs are the full costs that would need to be met by Peabody, and are fully inclusive of VAT, consultancy costs and contingency costs.

	Average per dwelling treated	Average for all estates
Fabric	£7,995	£6,257
Communal	£5,862	£3,096
Renewables	£10,665	£6,038
TOTAL	£24,521	£15,391

Table 6.10 Capital costs of refurbishment

The expenditure for different types of stock is shown in Table 6.11 using the SD scenario as a representative example (full costs are shown, prior to any grant funding). Total costs are around £20,000 in all cases, with the exception of Scattered estates which have far greater roof space available for solar PV. Fabric measures are most costly on Old estates and Scattered estates, which typically require solid wall insulation and on Electric estates where it is assumed that electric storage heating is replaced with gas central heating.

Classification	No. Units	Average cost per home treated			TOTAL
		Fabric measures	Communal measures	Renewables measures	
Recent Estates (1951 - 1991)	2304	£3,057	£5,508	£10,300	£18,865
Old Estates (pre-1951)	8210	£8,379	£6,028	£6,501	£20,908
Electric	456	£7,101	£7,690	£8,742	£23,533
Modern Estates (post-1991)	2351	£2,391	£7,632	£8,986	£19,009
Scattered	2981	£8,621	£5,096	£23,947	£37,664

Table 6.11 SD scenario: average capital costs by refurbishment approach

6.3.3 *NPV of refurbishment*

6.3.3.1 NPV Results

The results presented here show the NPV of refurbishment approaches *relative to* the Base approach. The results indicate that for each scenario modelled, the addition of each refurbishment package leads to a reduction in NPV (Figure 6.14). This result is particularly pronounced where solar thermal and solar PV is installed. It contrasts with the positive NPV typically associated with measures such as cavity wall insulation or draught-proofing, where a payback on the initial investment can be achieved within a small number of years. For the Fabric approach, which is the only refurbishment strategy delivering significant fuel bill savings to residents, this result illustrates that overall savings for residents are outweighed by the increased costs of refurbishment. If rents were raised to cover these refurbishment costs, residents would therefore be worse off overall in each scenario. The financial case for carbon reduction refurbishment, on the grounds of it being beneficial for Peabody and its residents overall, therefore appears not to exist for the measures and scenarios modelled.

The NPV values are significantly greater in the SD and PD scenarios due to the assumptions of considerable financial support for refurbishment, but this is not sufficient to make any approach financially attractive. Assumed discount rates are also a significant factor, with the lower rates assumed in the high fuel price scenarios putting an increased weight on future savings relative to initial capital costs. This leads to a greater NPV for the PD and BD scenarios relative to SD and KLO respectively.

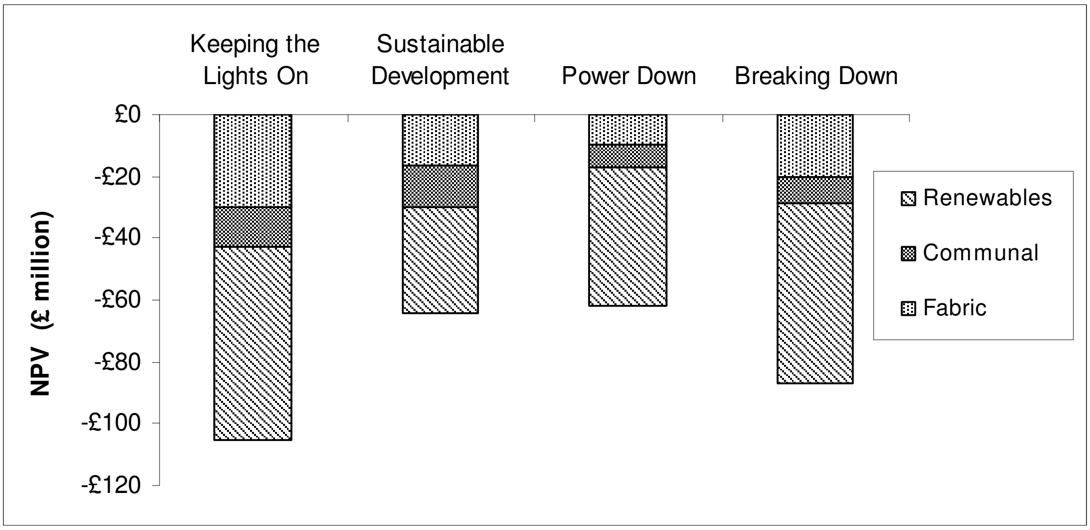

Figure 6.14 NPV by refurbishment approach

The results for Peabody NPV (Figure 6.15) show a similar pattern, with the only significant difference being the reduced NPV for the Fabric approach (as the financial benefits for residents are no longer taken into account). The finding that every approach has a negative impact on Peabody NPV indicates that of those considered, the current approach to refurbishment is the least-cost option for Peabody in each scenario over the long term.

Peabody NPV for the approaches that meet the GLA target are as follows: -£34 million for the Communal approach in Power Down; -£78 million for the Renewables approach in Sustainable Development; -£80 million for the Renewables approach in Power Down. These approaches therefore each have a significantly detrimental financial impact for Peabody, and present a challenging funding gap that needs to be bridged if they are to be realised.

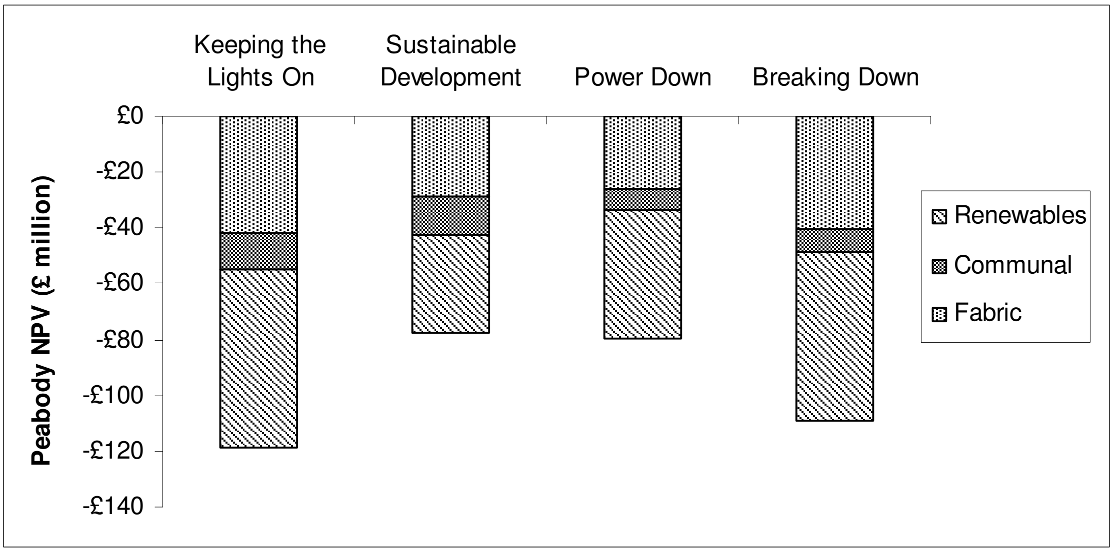

Figure 6.15 Peabody NPV by refurbishment approach

6.3.4 Sensitivity analysis

6.3.4.1 Most significant variables

The ten most significant variables for Peabody NPV are shown in Figures 6.16 and 6.17, which are representative of the results across all four scenarios. The two most significant factors are costs for solar PV and available roof space for solar panels, reflecting the impact of solar PV installation costs. Levels of grant funding have a significant impact, both in terms of Low Carbon Zone funding and grants for renewables. CHP costs have significant uncertainty attached. The size of terminal values is a methodological assumption that relates to the value ascribed to technologies that have further years of their expected lifespan remaining in 2030, and has a significant impact.

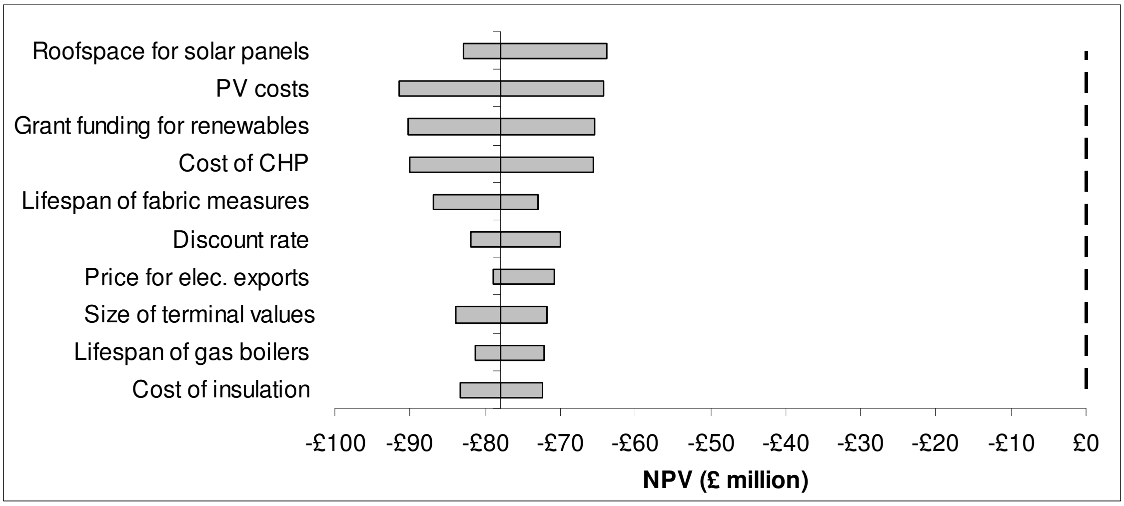

Figure 6.16 SD Renewables sensitivity analysis for Peabody NPV

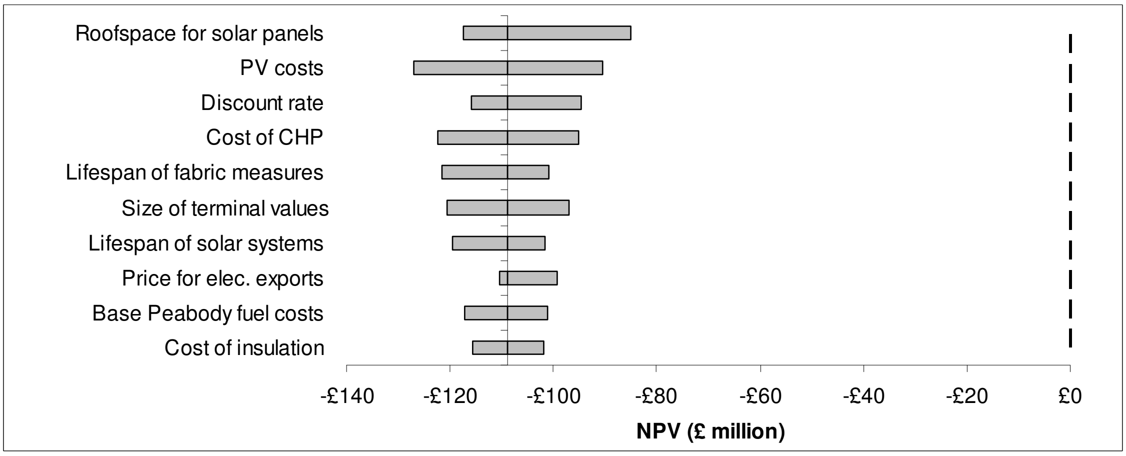

Figure 6.17 BD Renewables sensitivity analysis for Peabody NPV

The most significant variables affecting NPV for the Renewables approach are virtually identical in order and magnitude as for Peabody NPV. Figure 6.18 below shows the changes for the Communal approach in the PD scenario, where a zero NPV is close to being achieved. Increased grant funding, reduced CHP costs or a lower discount rate would all take the NPV close to zero, and together could create a financial case for an approach that meets the GLA target (albeit with a low degree of confidence).

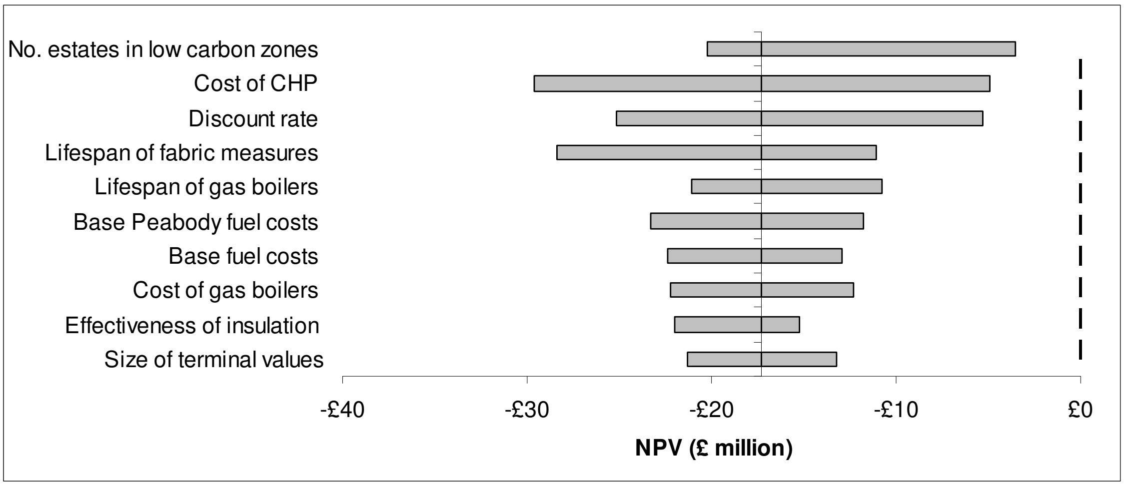

Figure 6.18 PD Communal sensitivity analysis for NPV

6.3.4.2 Results by approach

The results for Peabody NPV (Figure 6.19) indicate that, despite significant uncertainty about the results, the conclusion that Peabody NPV is negative for each approach and scenario considered appears to be robust.

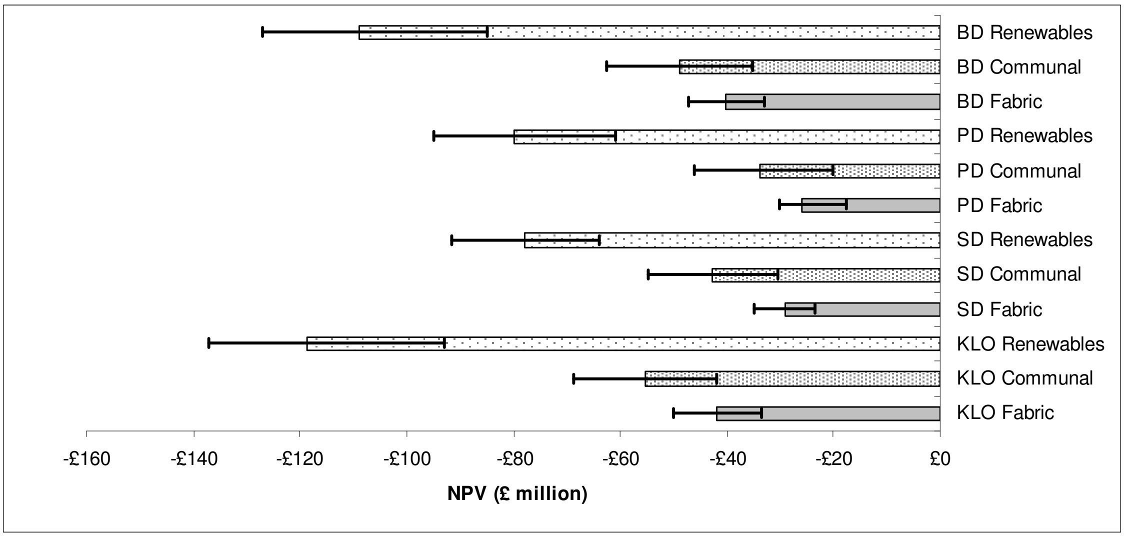

Figure 6.19 Sensitivity analysis for Peabody NPV

For NPV, the results indicate that a zero NPV is not likely for any of the scenarios considered, (Figure 6.20). However, as discussed above, a number of changes to assumptions in the PD scenario could make the achievement of the GLA target cost effective through the Communal approach.

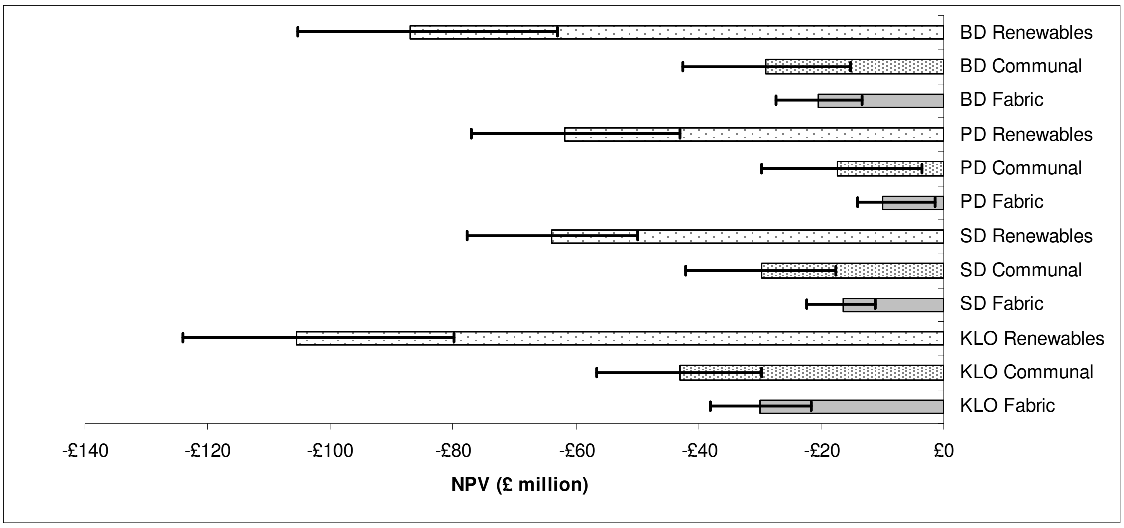

Figure 6.20 Sensitivity analysis for NPV

6.3.4.3 Values required for zero NPV

The values required for four scenario-related assumptions to give a zero Peabody NPV and a zero NPV for Peabody were calculated. These were the assumed discount rate, changes in fuel costs, costs of all refurbishment measures, and costs of alternative measures (technologies not used in the Base approach, such as CHP or solar thermal).

For Peabody NPV, achieving a zero result through changing these variables requires values that are extremely unlikely to be realisable. The results for the four scenarios include: annual fuel cost increases in the range 19% to 30%; refurbishment costs being reduced by 78% to 98%; costs for alternatives being reduced by 49% to 77%; a discount rate between -3.5% and -7.7%; grant funding covering 65% to 89% of costs.

For NPV, the values required for the three approaches that meet the 2025 target are shown in Table 6.12. The results for the Communal approach in the PD scenario show that if the costs of CHP and district heating are 25% less than the values assumed in this research (which is a possibility due to the significant uncertainty that exists), then that approach could be cost effective overall. With the possible exception of intervention costs, the other figures for this approach and for the Renewables approaches may be too extreme to be realistic. For example, a 7% per annum fuel cost increase leads to 2030 costs over 4.5 times greater than 2008 levels.

	PD Communal	PD Renewables	SD Renewables
Discount Rate	-0.7%	-3.0%	-2.8%
Fuel Costs	+7% per annum	+11% per annum	+12% per annum
Costs of all measures	-40%	-61%	-63%
Costs of alternatives	-25%	-49%	-52%
Grant funding	56%	65%	69%

Table 6.12 Values required to meet the GLA target with zero NPV

6.3.5 Shadow Price of Carbon

By attributing a value to carbon emission reductions using Defra's SPC, the value to society as a whole of carbon reduction strategies can be assessed. The implications of using the SPC were explored for NPV and Peabody NPV, and the level of SPC required to give a zero NPV was also calculated.

6.3.5.1 Results for NPV

Using the SPC has a relatively low impact on the majority of NPV outputs (Figure 6.21), which are increased by up to £5 million for each case considered. The order of preference of refurbishment options within scenarios is unaffected. Error bars show the impact of using the maximum and minimum proposed values for SPC described in 5.10.5. Even with a maximum value, NPV is also negative in every case. The SPC required to give a zero NPV (Table 6.13) is some way beyond the range of suggested values studied.

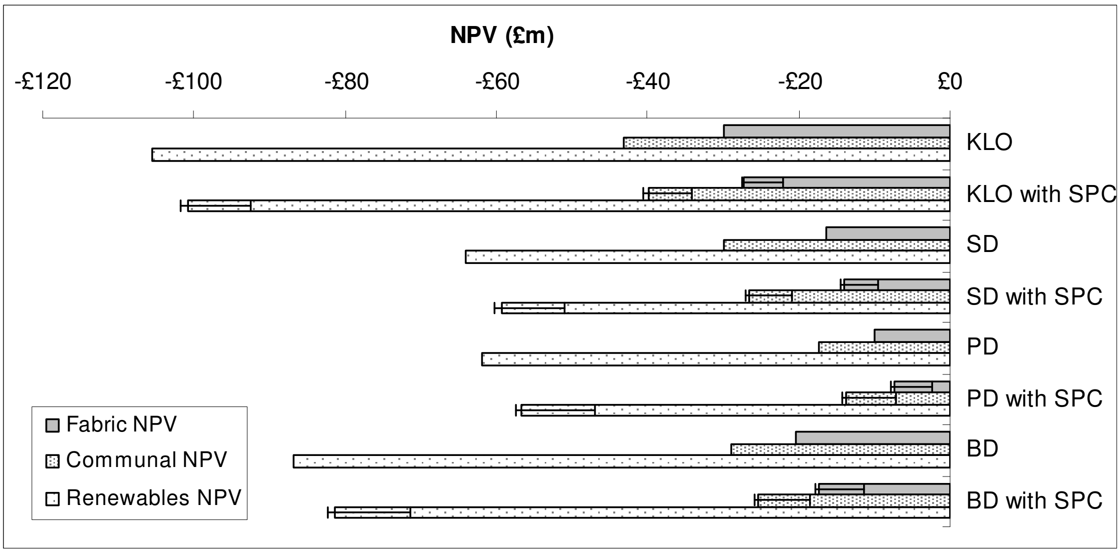

Figure 6.21 Impact of Shadow Price of Carbon on NPV

	KLO	SD	PD	BD
Fabric	£296	£181	£100	£174
Communal	£370	£253	£130	£213
Renewables	£624	£378	£320	£431

Table 6.13 SPC required (in 2011) to give zero NPV

As Peabody NPV is substantially lower than NPV in each case, applying the SPC does not lead to a positive Peabody NPV for any approach or scenario considered. To achieve a zero NPV for Peabody, an SPC in the range £255 - £702 per tonne of CO_2 would be required (Table 6.14), far beyond the range suggested in the literature to date.

	KLO	SD	PD	BD
Fabric	£414	£319	£258	£341
Communal	£474	£361	£255	£361
Renewables	£702	£460	£413	£540

Table 6.14 SPC required (in 2011) to give zero Peabody NPV

6.4 Summary

Four refurbishment approaches have each been considered under four future scenarios for Peabody stock. The resultant carbon emissions, resident fuel costs and financial impacts for the period up to 2030 have been quantified.

For carbon emissions, the key result is that the GLA target is only achieved in the Sustainable Development or Power Down scenarios. Even where the most comprehensive refurbishment approach is used, the target is not achieved in the Keeping the Lights On and Breaking Down scenarios. This highlights the need for change external to Peabody for deep carbon emission cuts to be achieved. Sensitivity analysis identified reduced energy demand and decarbonised grid electricity as the two key external contextual changes required. The GLA target is achieved through the Communal and Renewables approaches for Power Down, and only for the Renewables approach for Sustainable Development. To take into account uncertainty about model results, the concept of meeting the target with a "good degree of confidence" was put forward. Only the Renewables approach in Power Down achieves this.

Resident fuel costs increase in every scenario if fabric improvements are not carried out, due to assumed increases in fuel prices. Fuel poverty levels in 2030 are kept at similar levels to the present day through fabric improvements for all scenarios except Breaking Down. Sensitivity analysis indicated that if fuel prices stay stable at present day levels, fabric improvements can virtually eliminate fuel poverty on Peabody estates.

The findings relating to the financial impacts of refurbishment reveal that from Peabody's perspective, every approach brings a significant increase in expenditure, and has a negative NPV. This implies that the approaches considered cannot be carried out by Peabody unless extra funding is secured. NPV was also negative for Peabody and its residents considered as a whole in every case. This indicates that overall savings for residents are outweighed by the increased costs of refurbishment. As a result, if rents were raised to cover these refurbishment costs, residents would be worse off overall in each scenario. Only the Communal approach in the Power Down scenario met the GLA target and had an NPV close enough to zero that it could potentially be made positive by a number of changes in contextual factors.

The impact of attributing a value to CO_2 emission reductions was explored using Defra's Shadow Price of Carbon. It was found that both NPV and Peabody NPV are still negative for every approach in every scenario where it is considered. It therefore does not create a case for refurbishment beyond Peabody's current planned approach.

Chapter 7: Further analysis of model results

This chapter provides further analysis of the Peabody Energy Model results by exploring in more depth the impacts of particular interventions (7.1), identifying the effects of changing contextual factors on model outputs (7.2), and exploring approaches for meeting carbon reduction targets. Technical and financial strategies for meeting the GLA target are put forward in section 7.3 and the viability of meeting the zero-carbon target by 2030 is explored in section 7.4. The key findings from the chapter are summarised in section 7.5.

7.1 Impacts of interventions

This section explores the impacts of particular interventions by firstly identifying the cost-effectiveness with which they achieve emission reductions and then by identifying the impacts of changing refurbishment approaches so that different interventions are employed. The latter discussion summarises more detailed analysis reported in Reeves (2009).

7.1.1 Cost-effectiveness of approaches and measures

The cost-effectiveness of each measure considered for reducing carbon emissions was assessed, so that this information could be used to identify the most cost-effective approaches to meet the GLA target for each scenario. This was achieved by calculating the change in NPV and Peabody NPV brought about through each measure for each tonne of CO_2 saved in the period 2011 to 2030.

7.1.1.1 Results

The results indicate that none of the measures considered have a positive NPV from Peabody's perspective in any of the scenarios considered (Table 7.1). The cost-effectiveness varies significantly across scenarios due to factors such as different levels of grant funding for measures and differing changes in fuel costs and demand for energy. The most cost-effective measures include fabric improvements, biomass boilers and district heating. For solar PV, NPV and Peabody NPV are identical in each case as it is assumed that all electricity generated is sold to the grid, so residents do not benefit financially from its installation.

Measure (or Approach)	KLO		SD		PD		BD	
	NPV	Peabody NPV	NPV	Peabody NPV	NPV	Peabody NPV	NPV	Peabody NPV
Fabric	-£250	-£350	-£154	-£271	-£100	-£258	-£184	-£361
Fabric with decanting (relative to Fabric)	-£725	-£832	-£450	-£567	-£218	-£373	-£674	-£864
Fabric measures in voids	-£109	-£214	-£77	-£190	£8	-£148	-£7	-£200
CHP	-£1081	-£1097	-1553	-£1594	-£1098	-£1154	-£740	-£761
District Heating	-£450	-£460	-£230	-£236	-£102	-£111	-£337	-£351
Solar PV	-£1017	-£1017	-£580	-£580	-£779	-£779	-£949	-£949
Solar Thermal	-£884	-£984	-£461	-£565	-£496	-£636	-£803	-£984
GSHPs	-£3097	-£2604	-£674	-£398	-£710	-£299	-£3642	-£2822
ASHPs	N/A[1]	N/A[1]	-£1687	-£782	-£2491	-£1087	N/A[1]	N/A[1]
Biomass Boilers	-£280	-£284	-£269	-£276	-£238	-£248	-£265	-£270

Table 7.1 Change in Peabody NPV per tonne of CO_2 saved

Considering the NPV for Peabody and its residents as a whole, measures that reduce resident fuel costs have a higher NPV. As a result, fabric measures in void dwellings (comprising internal insulation and ventilation) have an NPV close to zero in the PD and BD scenarios. Conversely, installations of heat pumps have a significantly more negative NPV, due to resident fuel bills increasing as a result of a switch from gas to electricity as a fuel. Removing residents from their homes ("decanting") to install insulation is significantly less cost-effective than the alternative of insulating voids, but more cost-effective than CHP, solar thermal or solar PV.

Of the communal heating measures, district heating connections are considerably more cost-effective than CHP installations. This is despite capital costs being greater for district heating, and is due to assumed lower maintenance costs and the greater emission reductions achieved. Solar PV and solar thermal are found to be two of the least cost-effective measures, although due to the assumed grant support, they are each more cost-effective than gas-fired CHP.

The cost-effectiveness of Ground source heat pumps (GSHPs) varies significantly by scenario. They are an expensive way of reducing emissions in the KLO and BD scenarios, and a relatively cost-effective measure in the PD and SD scenarios, where significant grant funding and greater grid decarbonisation are assumed. Air source heat pumps (ASHPs) are

[1] "N/A" indicates that the approach leads to a net increase in emissions

less cost effective than GSHPs due to their lower efficiency. In the KLO and BD scenarios, due to lower assumed grid decarbonisation, their installation increases emission levels.

7.1.1.2 Sensitivity analysis

The sensitivity of the conclusions on cost-effectiveness to changes in model variables was explored using the sensitivity analysis approach introduced in 5.12.1. Figure 7.1 illustrates the results for the KLO scenario (representative of the findings from other scenarios), indicating the range of results achieved for each measure.

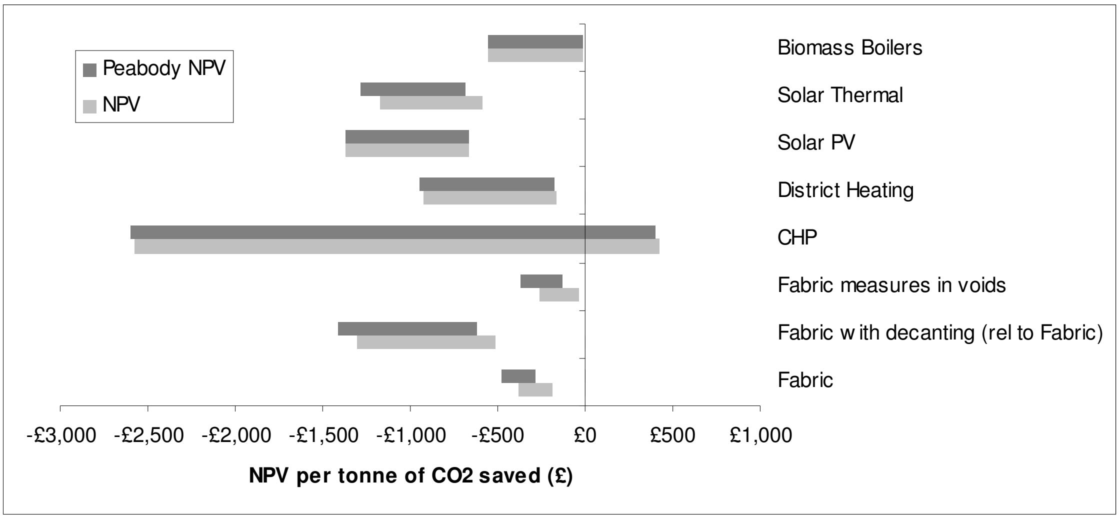

Figure 7.1 KLO scenario: uncertainty in NPV per tonne of CO_2 saved

The results show that there is significant uncertainty around the cost-effectiveness of CHP. This is due to the considerable range of possible capital costs assumed to be required for CHP installations. If CHP installation costs were at the low end of the range considered, then the measure could potentially have a positive NPV. Conversely, if costs were towards the high end of the range, the measure would be extremely costly relative to other carbon reduction measures.

GSHPs do not feature in Figure 7.1 as they do not always lead to a reduction in emissions in the KLO scenario. The highest NPV achieved by GSHPs is -£1050, which is associated with the lower assumed limit in the carbon intensity of grid electricity. The same assumption leads to the only example of ASHPs reducing emissions in this scenario, with an associated NPV of -£2400.

For the remaining measures, the range of uncertainty is relatively low, and is insufficient in this scenario to lead to any other measure having a positive NPV. The broad preference for fabric improvements, biomass installations and district heating connections over solar PV and solar thermal appears to hold. However the uncertainty around costs demonstrates the importance of assessing the financial impacts of refurbishment on a case-by-case basis.

7.1.2 Changes in refurbishment approach

A number of changes to refurbishment approaches are reported here, summarising findings explored in more detail in Reeves (2009).

7.1.2.1 Passivhaus refurbishment

The concept of Passivhaus refurbishment (Energie Institut 2007) was explored in Reeves (2009) through an Advanced Fabric approach, so that the highest possible levels of insulation and airtightness were achieved, therefore minimising space heating requirements. It was found to be extremely expensive relative to other carbon reduction measures, reducing NPV for Peabody by between £170 million and £240 million. The impact on carbon emissions was relatively low, with further reductions in the range 1-2% beyond those achieved by decanting residents to install internal insulation.

The measure was not effective at reducing fuel costs – indeed, in the PD and SD scenarios, where the increase in electricity prices is high relative to gas prices, the increased spending on electricity to power mechanical ventilation with heat recovery units over-rides the savings in space heating costs, leading to a net increase in average fuel costs. Overall, the failure of Passivhaus refurbishment to achieve cost-effective emission reductions can be attributed to the diminishing returns that are realised when applying additional insulation measures to well-insulated homes.

7.1.2.2 Communal heating approach

The greatest impact from communal heating was found to come from district heating connections. The impact on emissions of installing CHP on estates is very low, reducing emissions by approximately 0.5% in each scenario. The low reductions are due to grid decarbonisation in each scenario, reducing the carbon savings associated with displacing grid electricity. This effect means that by 2029 in the PD and SD scenarios, installing CHP on an estate is a higher-emission option than continuing to use individual gas boilers. The financial implications of CHP installations depend on the method of selling CHP electricity.

If this electricity is sold to the grid instead of being sold to residents as assumed, the NPV for Peabody would be decreased by between £5-9 million.

Communal biomass boilers lead to greater emission reductions than CHP, achieving cuts of 3% in each scenario. There is little difference between the costs for installing CHP or biomass boilers, so the greater emission reductions from biomass boilers make them a much more cost-effective carbon reduction measure.

7.1.2.3 Approach to solar installations

If solar PV and solar thermal are each used to the maximum possible extent, overall emission reductions are increased by 7% in each scenario. Solar thermal only contributes between 1-2% towards that total, so the majority of emission reductions achieved come from solar PV installations. This result is due to its more extensive application, as for the figures used in this research, solar thermal has a greater impact in reducing emissions for each square metre of roof space covered. Resident fuel costs and fuel poverty levels are largely unaffected by the approach taken to solar installations, as only solar thermal provides a fuel cost reduction, and only to a small number of residents.

7.1.2.4 Heat pumps

It was found that GSHPs and ASHPs only achieve significant emission reductions and reasonable cost-effectiveness when installed in scenarios defined by low carbon grid intensity. Their installation leads to increased fuel costs for residents, creating a likely conflict between carbon emission reduction and fuel poverty reduction. The emission reductions achieved are low: for GSHPs, up to 1% across the whole stock and up to 6% for treated estates; for ASHPs, up to 0.4% for across the whole stock and up to 3% for treated estates.

7.1.2.5 Electric heating

The prospect of substantial grid decarbonisation by 2030 presents the possibility that retaining or installing electric heating could be a beneficial carbon reduction measure. Electric heating is found to bring about slightly lower carbon emissions in 2030 in the SD and PD scenarios relative to the use of gas boilers, but greater emission levels in other scenarios. The emission-related benefits of replacing storage heaters depend strongly on the future carbon emissions associated with grid electricity. Retaining electric heating reduces refurbishment costs for Peabody by up to £3 million, but increases fuel bills and fuel poverty levels for residents.

7.2 Contextual factors

A number of contextual factors relevant for this research were explored through the model. These include the impact of: changing planning regulations on the use of solid wall insulation and micro-generation measures; allowing decanting of residents to treat whole estates with internal insulation; treating estates with insulation by 2016 to combat fuel poverty; reducing VAT rates for refurbishment.

7.2.1 Use of solid wall insulation

The scenarios modelled make the conservative assumption that solid walls are not insulated externally on listed estates or estates in conservation areas, due to concerns about maintaining the appearance of architecturally-significant buildings. Furthermore, internal insulation (for solid walls and floors) is only installed in void properties as they become available so as to avoid the extra costs and disruption involved with decanting residents from their homes.

The impact of three possible changes of assumptions regarding the Fabric approach are explored here: assuming that internal insulation is not installed in void dwellings at all; assuming that decanting is possible (so that whole estates can be decanted and then refurbished using internal wall insulation); assuming that there are no conservation area constraints, so estates in conservation areas (but not listed estates) can be externally insulated.

The impact of the considered changes is very similar for all the scenarios and approaches considered. Results are shown below for the Renewables approach in each scenario, and also for the only other two cases where the changes affect the achievement of the 2025 target (Figure 7.2).

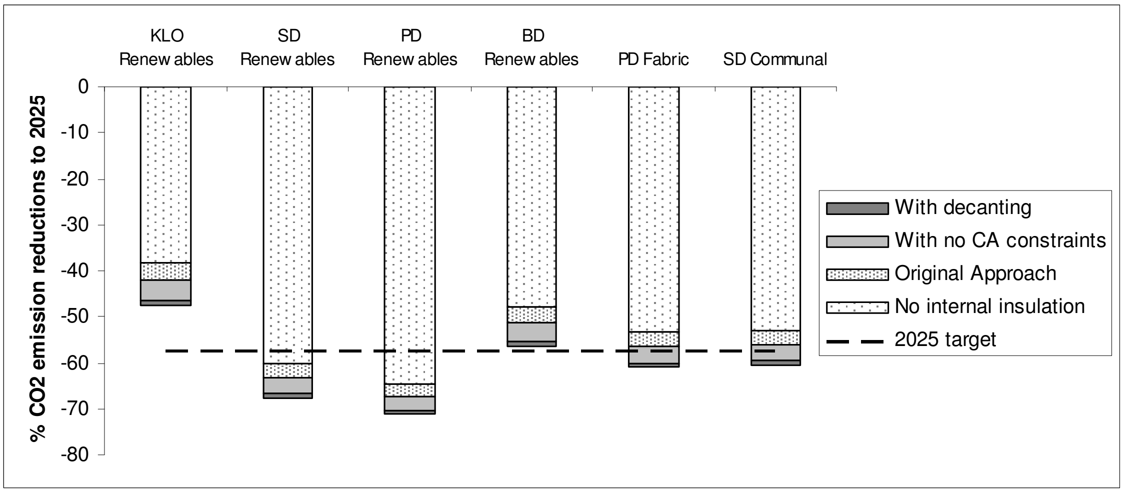

Figure 7.2 Impact of changing approach to solid wall insulation on CO_2 emissions

If internal insulation is not installed in void properties, this leads to the emission cuts achieved by 2025 being reduced by approximately 3% in each case. Decanting residents or externally insulating conservation area estates has very similar impacts — cuts of around 5% for the former and 4% for the latter — as in both cases the majority of solid-walled homes receive installation. Emission reductions are slightly greater where decanting is possible, as this change enables floor insulation to be installed, and for all estates to be insulated (homes on listed estates remain untreated where only the conservation area constraint is removed).

By either decanting residents or insulating externally, the Fabric approach in the PD scenario and the Communal approach in the SD scenario are both able to meet the 2025 target. This is significant because, as discussed in 7.1, insulation with decanting appears to be a more cost-effective carbon reduction measure than renewables or CHP in each scenario. This implies that when devising strategies to cost-effectively meet the GLA target, more-extensive solid wall insulation is likely to be preferable to the use of CHP or micro-generation.

The impact of changed insulation approaches on residents' fuel costs in 2030 is illustrated for a high fuel cost scenario (PD) and a low fuel cost scenario (KLO) for Peabody stock as a whole and for residents on affected estates (Table 7.2). Relative to a case where no insulation is installed, decanting residents to install internal insulation on conservation area estates leads to reductions in fuel poverty levels by over 3% and average fuel bill savings of around £130. Around half of this benefit is realised by installing insulation in void dwellings in the period up to 2030. The impact on overall Peabody fuel poverty levels is lower, as conservation area estates make up less than half of Peabody stock (approximately 44%).

Scenario and Package	Original 2030 fuel costs	2030 fuel costs with no internal insulation	2030 fuel costs with no Conservation Area constraints	2030 fuel costs with decanting
KLO Fabric – all estates	£775 (5.0% FP)	£805 (5.6% FP)	£752 (4.4% FP)	£747 (4.2% FP)
KLO Fabric – CA estates	£777 (6.8% FP)	£842 (7.2% FP)	£728 (4.5% FP)	£715 (4.1% FP)
PD Fabric – all estates	£756 (4.5% FP)	£787 (5.2% FP)	£732 (3.9% FP)	£726 (3.7% FP)
PD Fabric – CA estates	£763 (5.4% FP)	£831 (6.9% FP)	£710 (4.0% FP)	£696 (3.6% FP)

Table 7.2 Impact of changing insulation approach on fuel costs and fuel poverty

7.2.2 A focus on fuel poverty

The impact of carrying out a rapid programme of fabric improvements is assessed in this section (7.2.2.1 to 7.2.2.3), with a view to eliminating fuel poverty on Peabody estates by 2016 so that the Government target of eradicating fuel poverty by that date can be met (Defra 2004a). It is assumed that all solid-walled dwellings receive insulation by 2016, with residents on estates in conservation areas being decanted so that their homes can be internally insulated. In addition, the cost-effectiveness of measures considered to reduce fuel poverty is assessed (7.2.2.4).

7.2.2.1 Results for fuel poverty

Rapid fabric improvements lead to fuel poverty being virtually eliminated on Peabody estates by 2016 for all scenarios except BD (Figure 7.3). Fuel poverty levels in these scenarios are 0.6% or below, which contrasts to a range of 1.5% to 2.4% achieved through the original Fabric approach.

The assumed rising fuel prices in each scenario lead to fuel poverty levels increasing again from 2016. If fuel prices were to instead remain steady from 2016, this would leave fuel poverty levels close to zero on Peabody estates for each scenario except BD. If fuel prices increase to a much greater extent, as is the case for BD, eliminating fuel poverty using insulation measures is unlikely to be feasible, although its extent can be reduced greatly.

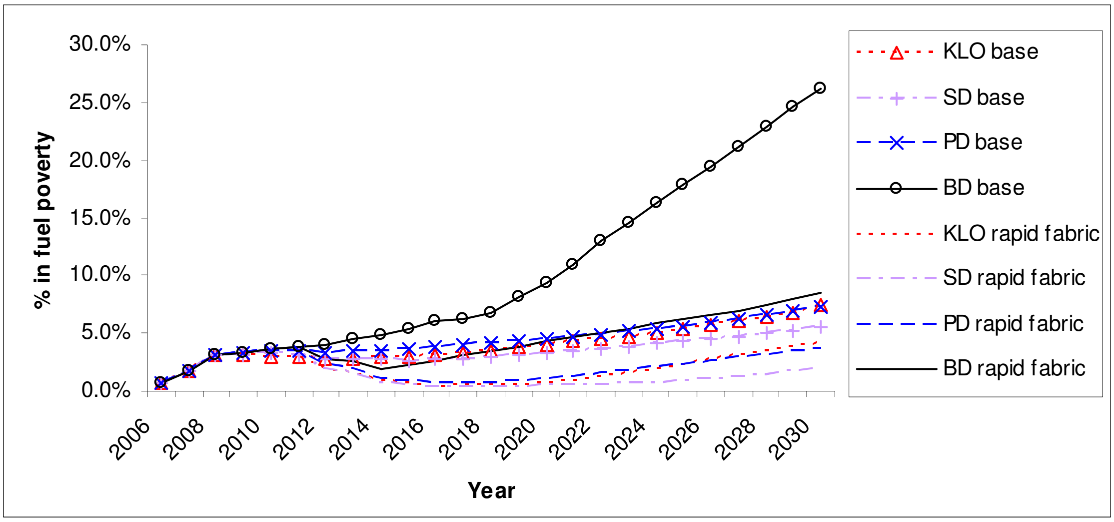

Figure 7.3 Impact of rapid fabric improvements on fuel poverty

7.2.2.2 Results for carbon emissions

A programme of rapid fabric improvements leads to a significant increase in the carbon emission reductions achieved by 2016 (Table 7.3). The reductions achieved to 2025 are the same as those achieved through a programme of decanting residents to insulate homes by that date. However, the more rapid emission reductions lead to total emissions being significantly reduced over the assessment period, making more rapid emission reductions a stronger approach from a climate change mitigation perspective.

	2016			2025		
	Base	Fabric	Rapid fabric	Base	Fabric	Rapid fabric
KLO	-16%	-24%	-37%	-19%	-33%	-39%
SD	-28%	-36%	-46%	-41%	-52%	-57%
PD	-28%	-37%	-46%	-46%	-56%	-61%
BD	-16%	-24%	-37%	-30%	-43%	-48%

Table 7.3 Emission reductions achieved after rapid fabric improvements

7.2.2.3 Results for NPV

Due to the front-loading of expenditure on stock improvements, a rapid programme of fabric improvements significantly decreases both NPV and Peabody NPV, and is therefore more challenging for Peabody to fund. The decrease in NPV is less than that for Peabody NPV in each case due to the extra savings in fuel bills achieved for residents.

	NPV (£million)			Peabody NPV (£million)		
	Fabric	Fabric with decanting	Rapid fabric	Fabric	Fabric with decanting	Rapid fabric
KLO	-£30m	-£63m	-£81m	-£42m	-£80m	-£103m
SD	-£16m	-£40m	-£49m	-£29m	-£58m	-£70m
PD	-£10m	-£22m	-£27m	-£26m	-£46m	-£53m
BD	-£20m	-£50m	-£63m	-£40m	-£78m	-£97m

Table 7.4 Impact of rapid fabric improvements on NPV

7.2.2.4 Cost-effectiveness of fuel poverty reduction measures

The cost-effectiveness of measures that reduce fuel poverty on Peabody estates was assessed by calculating the change in NPV for Peabody for each £1 saving in resident expenditure on fuel (discounted to 2011 prices) over the period 2011 to 2030. The same discount rate that was applied to Peabody expenditure was also applied to resident expenditure on fuel in each scenario, to take into account a preference for achieving savings nearer to the present day. An overall NPV of zero would equate to a £1 reduction in Peabody NPV to bring about a £1 saving for residents. As a result, a Peabody NPV of less than -£1 indicates that Peabody expenditure exceeds resident savings.

The results show that with one exception, each approach to fuel poverty reduction requires expenditure that exceeds the savings for residents (Figure 7.4). The only exception to this is installing insulation in voids, which has an overall NPV close to zero in the PD and SD scenarios. The measures considered are more cost-effective in scenarios where they are supported by grant funding (SD and PD) and in scenarios with low discount rates (PD and BD). Both the replacement of electric heating and solar thermal installations are shown to require many times more spending than they save for residents in reduced bills.

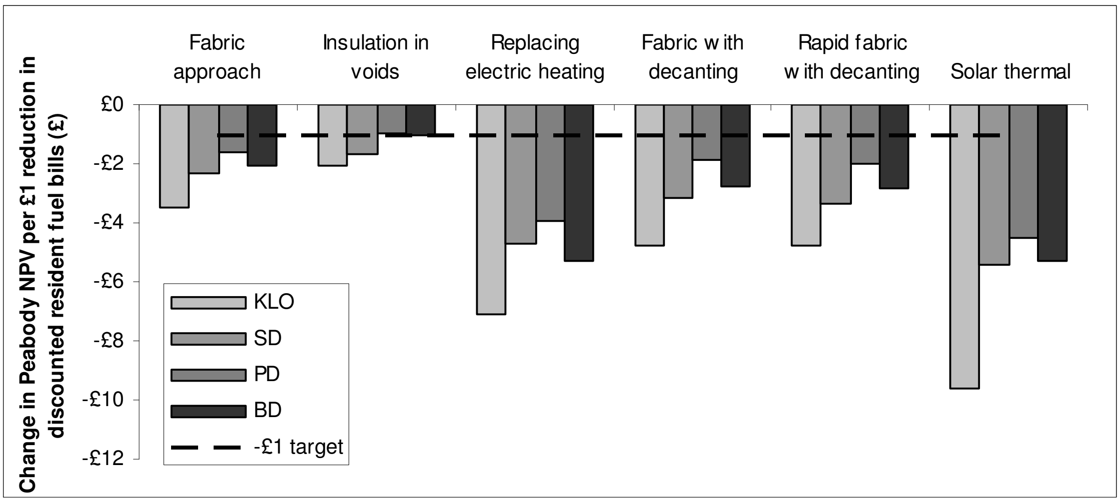

Figure 7.4 Cost effectiveness of interventions to reduce fuel poverty

7.2.3 Removing conservation area constraints for solar PV and solar thermal

The results given so far for the Renewables approach assume that no solar PV or solar thermal panels can be installed on listed estates or estates in conservation areas, so as to maintain the external appearance of these buildings. This is a conservative assumption, as there are buildings now being refurbished in conservation areas where solar panels are permitted on roof space facing away from adjoining streets, and even some examples known to Peabody staff where they are fully visible to the public.

This section explores the implications of assuming that the constraints preventing installations of solar panels on estates in conservation areas are removed. Listed estates form a small minority of Peabody stock, and it is assumed that their appearance can not be substantially altered, meaning that solar PV and solar thermal still can not be installed.

The results indicate that allowing solar PV and solar thermal installations in conservation areas leads to increased emission reductions of 4% in each scenario (Figure 7.5). These further emission reductions greatly increase the confidence that the 2025 target is met for SD and PD, and reveal potential to achieve emission cuts beyond 70% by 2025. For the BD scenario, the modelled emission reductions are close to 57%, which, given the uncertainties in the model, indicates a chance that the 2025 target could be met.

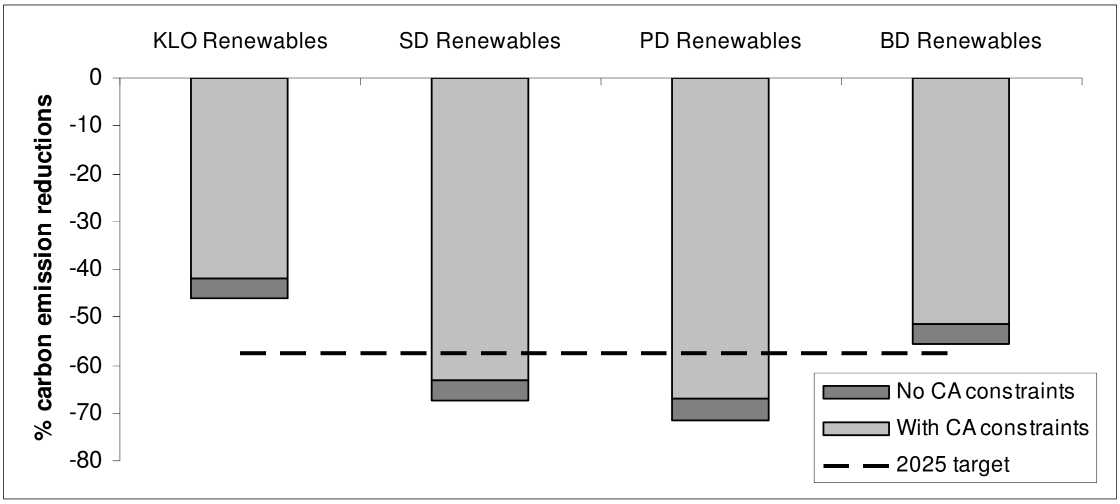

Figure 7.5 Impact of removing constraints on use of solar PV and solar thermal

Further installations of solar PV and solar thermal have a significant impact on NPV for Peabody, leading to reductions of between £22 million and £36 million. The reductions in

NPV are greatest in those scenarios where renewables receive the least grant funding support and do not benefit from FITs or declining installation costs. The overall impact on resident costs and fuel poverty is minor, reducing average costs by £5-8, due to only solar thermal leading to reduced fuel bills, and the relatively low amount of solar thermal installations

7.2.4 Reduced VAT rates for refurbishment

Reduced rates for VAT for housing refurbishment measures have been called for by a number of bodies, in particular to improve the financial case for retrofitting relative to demolition and rebuild (SDC 2006a; CLG Committee 2008). A number of the measures considered — insulation, solar PV, solar thermal and heat pumps — are already rated at 5% VAT (HM Revenue and Customs 2006). The impact of rating capital costs for all other measures at 5% on the cost-effectiveness of refurbishment was investigated.

The impact on Peabody NPV of a reduced VAT rate is of the order of £1-4 million across the four scenarios, being greater in scenarios where less grant funding was available (Table 7.5). This change makes little difference to the overall viability of funding refurbishment for Peabody, as NPV is significantly negative in each case.

	KLO	SD	PD	BD	Average
Fabric	£2.4m	£1.7m	£1.7m	£2.5m	£2.1m
Communal	£4.1m	£3.6m	£3.2m	£3.9m	£3.7m

Table 7.5 Reduction in Peabody NPV due to lower VAT rate

7.3 Meeting the GLA target

The prospects for meeting the GLA carbon reduction target are assessed in this section for each scenario, with approaches and funding strategies for meeting the target put forward where the target can be achieved.

7.3.1 Keeping the Lights On

As discussed in chapter 6, the model results indicate that with the constraints assumed in the KLO scenario, the GLA's carbon reduction target can not be met. Using the assumption that constraints external to Peabody cannot be changed, but allowing Peabody's own approach to be improved, the viability of meeting the 2025 target was explored. If the constraint on decanting residents is removed, emissions reductions can be increased from 42% to 47.5% for the Renewables approach. If Biomass boilers are installed instead of

CHP this increases to 51.2%. This is the limit of reductions that can be achieved through Peabody's efforts alone. The 2025 target of a 57.4% reduction in emissions is therefore not achieved. With a shortfall of more than 6%, this conclusion is likely to be robust, even where uncertainties affecting model results are taken into account.

7.3.2 Sustainable Development

For this scenario, the 2025 target is met relatively comfortably for the Renewables approach, and was close to being achieved for the Communal strategy. Based on the issues discussed in chapters 6 and 7, a number of methods are put forward to meet the 2025 target (Table 7.6). These approaches were also assessed for the cost-effectiveness with which they reduce emissions (Table 7.7), using the same method as that used for individual measures in section 7.1.

Approach	Description	CO_2 Emission Reductions to 2025	NPV	Peabody NPV
Biomass	Fabric; District Heating; Biomass boilers	59%	-£30 million	-£43 million
Decanting	Fabric with decanting; District Heating	60%	-£46 million	-£64 million
Solar PV	Fabric; District Heating; Solar PV	62%	-£56 million	-£68 million
Renewables	Fabric; CHP; District Heating; Solar PV; Solar Thermal	63%	-£64 million	-£78 million
Good Confidence	Fabric with decanting; District Heating; Solar Thermal; Biomass boilers	65%	-£58 million	-£77 million
Rapid Good Confidence	Fabric with decanting by 2016; District Heating; Solar Thermal; Biomass boilers	65%	-£67 million	-£89 million
Maximum	Fabric with decanting; Biomass boilers; District Heating; Solar PV; Solar Thermal; Ground Source Heat Pumps; Air Source Heat Pumps; Retained Storage Heaters	73%	-£99 million	-£111 million

Table 7.6 SD scenario: approaches to meet the GLA target

Approach	NPV per tonne of CO_2 saved	Peabody NPV per tonne of CO_2 saved
Biomass	-£183	-£261
Decanting	-£256	-£360
Solar PV	-£294	-£361
Renewables	-£321	-£391
Rapid Good Confidence	-£278	-£369
Good Confidence	-£262	-£350
Maximum	-£346	-£388

Table 7.7 SD scenario: cost-effectiveness of approaches to the meet the GLA target

The approach that is most cost-effective for Peabody is “Biomass”, which comprises fabric improvements, biomass boiler installations and district heating connections. If biomass boilers can not be installed, the “Decanting” or “Solar PV” approaches have similar impacts in terms of costs-effectiveness for Peabody, although greater emission reductions are achievable through the latter. The original Renewables approach achieves 63% reductions, and reductions of up to 73% are achievable by 2025 through the “Maximum” strategy that applies all possible measures.

Considering the likelihood that a strategy is successful given the uncertainties in the model, a “Good Confidence” approach was also devised. This is the most cost-effective refurbishment strategy for which the 2025 target is still met even if demand for energy (the most significant factor identified in the sensitivity analysis) is at the upper bound considered for this scenario. The Good Confidence approach for this scenario comprises fabric improvements with decanting, district heating, solar thermal and biomass boiler installations. As the most cost-effective measures are selected, it achieves greater emission reductions than the Renewables strategy and with a greater NPV per tonne of CO_2 saved.

Taking into account the benefits of a rapid programme of fabric improvements identified in 7.2.2, a Rapid Good Confidence method was also devised, which extends the Good Confidence approach by carrying out all fabric improvements by 2016. This method has an NPV for Peabody of -£89 million. Overall, the refurbishment strategies identified have an NPV for Peabody of between -£43 million and -£111 million, indicating a significant funding gap no matter which approach is pursued.

7.3.3 Power Down

The Power Down scenario is the most successful of the scenarios modelled in terms of emission reductions, due to the combination of low energy demand, increased availability of low carbon energy and strong support for carbon reduction measures. As a result, a number of distinct strategies are available to Peabody to meet the 2025 target (Table 7.8). Their cost-effectiveness in terms of NPV and Peabody NPV per tonne of CO_2 saved is shown in Table 7.9.

Approach	Description	CO_2 Emission Reductions	NPV	Peabody NPV
Solar Thermal	Fabric; Solar Thermal	58%	-£17 million	-£35 million
Heat pumps	Fabric; GSHPs	59%	-£22 million	-£31 million
District Heating	Fabric; District Heating;	60%	-£13 million	-£29 million
Communal	Fabric; CHP; District Heating	60%	-£17 million	-£34 million
Biomass	Fabric; Biomass boilers	61%	-£19 million	-£35 million
Decanting	Fabric with decanting;	61%	-£22 million	-£46 million
Solar PV	Fabric; Solar PV	63%	-£54 million	-£70 million
Good Confidence	Fabric with decanting; District Heating; Biomass boilers	67%	-£30 million	-£54 million
Rapid Good Confidence	Fabric with decanting by 2016; District Heating; Biomass boilers	67%	-£35 million	-£61 million
Renewables	Fabric; CHP; District Heating; Solar PV; Solar Thermal	67%	-£62 million	-£80 million
Maximum	Fabric with decanting; Biomass boilers; District Heating; Solar PV; Solar Thermal; GSHPs; ASHPs; Retained Storage Heaters	76%	-£87 million	-£103 million

Table 7.8 PD scenario: approaches to meet the GLA target

Approach	NPV per tonne of CO_2 saved	Peabody NPV per tonne of CO_2 saved
Solar Thermal	-£148	-£305
Heat pumps	-£185	-£261
District Heating	-£100	-£228
Communal	-£130	-£255
Biomass	-£137	-£255
Decanting	-£141	-£298
Solar PV	-£347	-£450
Good Confidence	-£148	-£267
Rapid Good Confidence	-£160	-£280
Renewables	-£320	-£413
Maximum	-£314	-£369

Table 7.9 PD scenario: cost-effectiveness of approaches to meet the GLA target

If applied alongside fabric improvements, a number of different technologies can achieve emission reductions of between 58% and 63% (Table 7.8). The District Heating, Biomass and Decanting strategies each perform strongly in terms of having relatively high values for NPV per tonne of CO_2 saved (Table 7.9).

If a good confidence of meeting the 2025 target is desired, the most cost-effective approach involves a combination of fabric improvements with decanting, district heating and biomass boilers. This is less extensive than for the SD scenario where solar thermal was also required. This approach is significantly more cost-effective than approaches which achieve comparable levels of emission reductions, due to not relying on solar PV installations. However, if deeper emission reductions are pursued, solar PV is likely to be required. The maximum reductions achievable by 2025 in this scenario are 76%, achieved by combining all reasonably cost effective measures, and resulting in an NPV for Peabody of just over -£100 million. The funding gap for the PD scenario is not quite as great as for SD, with NPV for Peabody ranging from -£35 million to -£103 million.

7.3.4 Breaking Down

Meeting the GLA target is highly challenging in the Breaking Down scenario. Taking the Renewables approach as a starting point, if the constraint on decanting residents is removed, emissions reductions to 2025 can be increased from 51% to 56.5%. If Biomass boilers are installed instead of CHP this increases to 60%. Only one refurbishment approach was therefore considered for this scenario (Table 7.10), a "Maximum" approach comprising all effective carbon reduction measures. An approach that gives a good level of confidence that the 2025 target is met does not exist for this scenario, as emission reductions beyond 62% would be required.

Approach	Description	CO_2 Emission Reductions	NPV	Peabody NPV	NPV per tonne of CO_2 saved	Peabody NPV per tonne of CO_2 saved
Maximum	Fabric with decanting; District Heating; Biomass Boilers; Solar PV; Solar Thermal	60%	-£120m	-£150m	-£463	-£577

Table 7.10 BD scenario: approach to meet the GLA target

The costs of this approach are substantial, with an NPV for Peabody of -£150 million for the Maximum approach. The NPV per tonne of CO_2 saved is - £463, some way in excess of the values identified for the SD and PD scenarios. Overall, for this scenario there is not a good degree of confidence that the approach considered would successfully meet the 2025 target, and its financial viability is in any case seriously doubtful.

7.3.5 Beyond the 2025 target

The 60% emission reduction goal set by the GLA is a milestone on an intended trajectory to still-greater emission cuts of the order of 80-90%, with further rapid reductions intended from 2025 to 2030 (GLA 2007). Furthermore, the evidence that there is greater potential to achieve deep emission cuts in less-efficient stock could imply that landlords such as Peabody should look to achieve reductions beyond any given percentage target applied to the housing sector. This also implies a need to assess the viability of achieving cuts that go beyond the GLA target.

New technologies may play a significant role in the period up to 2025 and afterwards in achieving emission cuts, but the results from this research can be used to judge the viability of achieving emission cuts of 80% or beyond using existing technologies. The greatest emission reductions achieved to 2030 for the initial modelled approaches was 71% for the Renewables approach in the PD scenario (Table 3.2). The Maximum approach for the PD scenario (described in 7.3.3) achieves an 85% reduction by 2030, if the additional assumptions are made that all gas central heating systems are removed and replaced with electric heating and that all gas cookers are replaced with electric models.

These results highlight that to go beyond the 2025 target, towards reductions in the range 80-90%, substantial further stock improvements may be required, which would need to include less cost-effective technologies such as solar PV. Emission targets on this scale would also put greater pressure on constraints external to Peabody, such as planning policies in conservation areas, levels of domestic energy use and the emissions associated with grid electricity.

7.3.6 Bridging the funding gap

The NPV results have demonstrated that each refurbishment approach that leads to the GLA target being achieved has a significantly negative NPV. This implies that a funding gap needs to be bridged by Peabody if any of the approaches studied are to be carried out. Additional funds of the order of tens of millions of pounds are likely to be challenging to generate through existing stock refurbishment budgets or by reducing budgets from other services. If existing internal resources are insufficient to fund this refurbishment and increased external support is not forthcoming, two principal options remain for Peabody — increasing rents or disposing of properties. In this section the implications of funding refurbishment through either of these approaches are explored to illustrate the potential scale of the impact on the organisation of meeting the GLA target.

7.3.6.1 Background and methods

Rent increases of 0.5% per year beyond inflation (plus an annual £2 increase on weekly rent levels) are already planned for Peabody properties for the foreseeable future. This is the maximum increase currently permitted by Government, and is in place to enable Peabody homes (which currently have relatively low rents for London social housing) to move towards target rents set by Government.

The annual rent increases (that go beyond this level) that would be required during the period 2011 to 2030 to give a zero NPV for Peabody for each successful refurbishment approach have been calculated. Whilst this illustrates the level of increases that would be required to fund the considered refurbishment approaches, it is acknowledged that this approach is not currently viable in the current regulatory climate. Where sales of Peabody stock are considered, it is assumed for simplicity that dwellings are sold prior to 2011. The number of Peabody dwellings requiring refurbishment and Peabody's rental income beyond that date are reduced accordingly. It is assumed that £210,000 is generated per unit sold, based upon current Peabody practice. Disposals of properties are currently planned to take place at Peabody as part of its asset management strategy, and these sales represent extra disposals beyond planned levels.

7.3.6.2 Results

Results were calculated for the three scenarios where strategies for meeting the GLA target were identified. For the SD scenario, the approaches considered require annual rent increases in the range 0.4% to 0.9% or between 290 and 730 sales of dwellings (Table 7.11). To meet the target with a good degree of confidence, an annual rent increase of 0.7% (leading to an overall 15% increase by 2030) or sales of 520 dwellings would be required. For the PD scenario, the range of rent increases or stock sales required to meet the 2025 target is lower, with an annual rent increase of between 0.2% and 0.7% or the sale of 210 to 720 units being required (Table 7.12). The Good Confidence approach would require annual rent increases of 0.4% (leading to an 8% increase by 2030) or sales of 360 units. For the BD scenario, the costs of meeting the GLA target are more prohibitive, with 1050 stock sales being required or annual rent increases of 1%.

	Biomass	Decanting	Solar PV	Renewables	Good Confidence	Rapid Good Confidence	Maximum
Annual rent Increase	0.4%	0.6%	0.6%	0.7%	0.7%	0.8%	0.9%
Stock Sales	290	430	460	520	520	590	730

Table 7.11 SD scenario: funding methods to meet the GLA target

	Solar Thermal	Heat Pumps	District Heating	Communal	Biomass	Decanting
Annual rent increase	0.3%	0.2%	0.2%	0.3%	0.3%	0.3%
Stock sales	250	220	210	240	250	330
	Solar PV	Good Confidence	Rapid Good Confidence	Renewables	Maximum	
Annual rent increase	0.5%	0.4%	0.6%	0.6%	0.7%	
Stock Sales	500	390	560	560	720	

Table 7.12 PD scenario: funding methods to meet the GLA target

7.3.6.3 Increasing rents towards target rents

Rents for Peabody residents are generally lower than for comparable social landlords in London (Housing Corporation 2008c). Government legislation on rent restructuring demands that rents in social housing should move towards Target Rents, specified using a Government formula, so that rents are at Target Rent levels by 2012 (ODPM 2003). In Peabody's case, due to currently low rent levels, this requires an increase in average rents. However, due to restrictions in the rent restructuring legislation described above, less than a third of Peabody homes are expected to be let at target rents by 2012 (based on information from Peabody).

The maximum limit on potential extra rental income available to Peabody can be identified by calculating the extra income (relative to current projected income) that is generated by a hypothetical immediate move to target rents. Using figures from Peabody, this move would generate extra income of £223 million up to 2030. By applying a discount rate to the increased cash flows, this income has a present value (in 2008) of £149 million with a discount rate of 3.5%, £176 million with a 2% discount rate, or £187 million with a discount rate of 1.5%. The income generated therefore comfortably exceeds the extra funds required to pay for stock refurbishment to meet the GLA target for the SD and PD scenarios. Clearly an immediate increase to target rents would not be viable in practice. However, this result implies that a staged increase at levels beyond those currently permitted by Government could theoretically be used to bridge the funding gap. In so doing, Peabody could be able to fund stock refurbishment without necessarily causing undue hardship for residents.

7.4 Achieving zero carbon emissions

To carry out this assessment, the most successful emission reduction scenario, Power Down, is taken as a starting point. The improvements that need to be made beyond this starting point to achieve net zero carbon emissions are then considered.

7.4.1 Estates achieving zero-carbon status in the Power Down scenario

After the application of the Renewables approach in the Power Down scenario, one Peabody estate achieves zero carbon emissions in 2030 (Hainton Close), with annual emissions per unit of minus 0.1 tonnes. This is achieved through an assumed connection to a district heating scheme, and a substantial installation of solar PV, which produces more electricity annually than is used on the estate (and is all exported to the grid). As energy derived from fossil fuels is either directly or indirectly supplying all Peabody estates in 2030, the approach that provided net zero emissions for Hainton Close, of offsetting emissions through generation of on-site electricity with solar PV, would also be required for any other Peabody estate to be zero-carbon.

The principal barrier to achieving this for Peabody stock is the relatively small amounts of roof space suitable for solar PV on its estates. This is a particular issue on Peabody's older estates, which are multi-storey and often have heavily shaded roofs, leading to a low area of roof space per dwelling. Only a fraction of this roof space will then by appropriately oriented for solar panels to be efficient, making the available area smaller still.

7.4.2 Achieving zero-carbon estates by 2030

The ability for Peabody stock to go beyond the levels of reductions described above using existing technologies will depend on three key assumptions: the carbon intensity of grid electricity; energy demand from residents; the viability of biomass CHP. Biomass CHP is important as it is the only technology apart from solar PV and gas-fired CHP that can be used on Peabody estates to offset emissions through the generation of electricity. At present, it is not considered to be a mature technology for applications on the scale of Peabody estates (RAB 2007), but this situation could change by 2030.

To assess the impact of reduced demand and reduced emissions from lower carbon communal heating, such as heating through biomass CHP, four approaches are considered (Table 7.13). The emission reductions achieved by 2030 through these approaches are shown in Table 7.14. The results indicate that even if maximum use is made of technical interventions and with significant energy demand reductions from residents, zero-carbon status is not achieved for Peabody stock.

Base	In which the assumptions in the Renewables approach of the PD scenario are used.
Maximum	As for the Maximum approach in 9.1.3 above. Furthermore, it is also assumed that gas boilers are replaced with electric storage heaters (as with the carbon intensity of grid electricity being below 0.2 gCO_2 /kWh in 2030 in each case, this is the lowest carbon option). It is also assumed that gas cookers are replaced with electric cookers in each home where gas heating is removed for the same reason.
Low Demand	As for the Maximum approach, but with resident demand for energy reduced to the lower limit used in the sensitivity analysis.
Low Demand and Biomass CHP	As for the Low Demand approach, but with biomass CHP installed instead of biomass boilers

Table 7.13 Approaches to achieve zero net carbon emissions

	Base	Maximum	Low Demand	Low Demand and Biomass CHP
2030 average emissions / t	1.0	0.5	0.4	0.3
% emission reduction	71%	85%	89%	91%

Table 7.14 Average annual emissions in 2030

A remaining approach to move towards zero carbon emissions would be to assume a reduced carbon intensity of grid electricity, beyond the already low figure for 2030 of 0.171 kg CO_2 per kWh (around 1/3 of present-day levels). However, reducing this figure towards zero does not lead to zero net carbon emissions being achieved. This is because when the emissions associated with electricity use are reduced, the carbon emission reductions that result from displacing grid electricity by on-site generation (through solar PV or biomass CHP) are also reduced. This leads to the conclusion that zero-carbon grid electricity is necessary to achieve zero carbon emissions, coupled with a modified approach to energy supply systems on Peabody estates.

7.4.3 Zero-carbon grid electricity

If grid electricity is produced entirely from zero-carbon sources, then if any fossil fuels are used either directly or indirectly to provide energy for Peabody estates, zero-carbon status can not be achieved. Achieving zero net carbon emissions in the context of a zero-carbon grid using existing technologies therefore requires the exclusive use of electricity or biofuels to provide energy for Peabody estates. Gas-fired individual heating systems could be replaced by electric heating, either in the form of storage heaters or, where feasible, heat pumps. Communal systems could only be used as part of a zero-carbon strategy if they could be fuelled entirely by biofuels, such as wood-chip or biogas.

Consideration of zero-carbon grid electricity can lead to results that seem counter-intuitive. For example, the Hainton Close estate described in 7.4.1 above which achieves zero-carbon status in the PD scenario loses this status as the carbon intensity of grid electricity approaches zero. This is due to the reduced emission cuts associated with displacing grid electricity and the continued use of natural gas as an input to the district heating scheme.

7.5 Summary

This chapter has studied the effectiveness of carbon reduction interventions, the impacts of changing refurbishment approaches and strategies for meeting carbon reduction targets.

The analysis of the cost-effectiveness of carbon emission reductions found that only internal insulation in void dwellings in the Power Down scenario has a positive NPV. Of the remaining measures, the Fabric approach, communal biomass boilers and district heating were the most cost-effective at reducing emissions. Solar PV and solar thermal were each very costly, although they could be made much more cost-effective by grant support. CHP was also very costly, although the sensitivity analysis revealed significant uncertainty about this conclusion. Decanting residents to install internal insulation was shown to be more cost effective and to benefit residents more financially than installing CHP, solar PV or solar thermal. Heat pumps performed poorly in the BD and KLO scenarios, but were relatively cost effective in the PD and SD scenarios where grid carbon intensity was lower and they received more grant support.

For all scenarios except Breaking Down, fuel poverty levels could be brought close to zero by 2016 through a rapid programme of fabric improvements. However, the assumption that fuel prices continue to increase beyond this date leads to increased fuel poverty levels in each scenario.

If the installation of solar panels is permitted on Peabody's estates in conservation areas, further emission reductions of up to 4% can be achieved, but these come at a substantial cost. The availability of reduced VAT rates for refurbishment was explored, and was found to have little impact on results, reducing NPV for Peabody by up to £4 million.

A number of approaches for meeting the GLA target in the SD and PD scenarios were put forward. Approaches that give a good level of confidence of meeting the target had an NPV of approximately minus £80 million for Peabody. The levels of stock sales or rent increases required to bridge the funding gap were calculated, leading to the finding that sales of up to 4% of Peabody stock or rent increases of up to 0.9% per year would be required. Rent increases were shown to have particular potential as a funding mechanism in Peabody's case due to currently low rent levels.

The zero-carbon target could only be achieved if zero-carbon grid electricity is available. This has the technical implication that only biofuels or electricity could be used to provide energy on Peabody estates.

Chapter 8: Participant observation study

This chapter presents the results of the participant observation study carried out from June 2006 to April 2009. Peabody's broad organisational context is first established in 8.1 with reference to: Peabody's recent history prior to the research period; internal priorities and key external issues identified during the research; relevant actions undertaken during the research period. Contextual factors affecting interventions are discussed in sections 8.2 to 8.8. Motivations for interventions are reported (8.2), followed by issues relating to internal resources: financial issues (8.3) and Peabody staff knowledge, skills, internal capacity (8.4). Other relevant internal factors such as staff views, internal processes and other organisational goals are discussed in 8.5. Issues relating to residents, including their priorities and the acceptability of interventions are reported in 8.6. Section 8.7 summarises contextual factors identified relating to particular technical interventions considered in this research. The main findings from the chapter are then summarised in 8.8.

Peabody staff are quoted throughout the chapter to provide support for the account put forward. Where this is done the date of the statement is given (for example "March 2008"), but the name or role of staff is not given to ensure anonymity.

8.1 Broad organisational context

8.1.1 Recent history

For several years prior to the research period, Peabody played an active and innovative role in efforts to mitigate climate change in housing. The most high-profile action was developing the BedZED estate in 2003, a pioneering attempt to construct zero-carbon new housing (Bioregional 2004). The potential for installing solar PV on Peabody estates was assessed in 2001 (Whitby Bird & Partners 2001), and was followed by a number of PV installations on existing estates carried out through the EU- funded Resurgence project (EESD 2002). Peabody actively participated in a number of research projects, including the CARRA study, on area-based efforts to reduce carbon emissions (Islington Council 2003), and a study by the Association for Conservation of Energy on energy use behaviour (ACE 2005a). As discussed in 1.6, from 2002 to 2003 Peabody commissioned research on long-term strategies for addressing fuel poverty and reducing carbon emissions from its stock, leading to the creation of the present PhD project and the parallel research conducted by Dwyer (forthcoming).

A poor outcome in an audit commission inspection in 2003 and the new requirement for Peabody stock to meet the Decent Homes standard by 2010 (ODPM 2004) brought about a significant shift in Peabody's organisational focus. Meeting the Decent Homes standard represented a considerable financial challenge, and to fund the work required, Peabody reluctantly decided to sell targeted stock as part of a "disposals" programme which will be ongoing to 2010 (Peabody Trust 2006). Reorganisation led to a significant number of redundancies and many of the staff that had driven Peabody's green agenda in previous years left the organisation.

8.1.2 From 2006 to the present day

Contact was first established by the researcher with Peabody in mid-2006 and has been frequent ever since. The key events that have taken place with regard to the conduct of the present research, internal action by Peabody and changes in external context are illustrated in Figure 8.1.

When contact was first established, good performance in an ongoing Audit Commission inspection was an over-riding strategic focus for the organisation. Following a successful outcome, in autumn 2006 there was a new focus within Peabody on "blue skies" thinking (Feb 2007), and the Chief Executive initiated new strategic work on sustainability. A key influence supporting this process was a talk given in October 2006 at Peabody by Allan Jones, Chief Executive of the London Climate Change Agency, which mobilised support for action on climate change amongst senior management.

Over the research period, there was a transformation in the internal focus on climate change and sustainability issues within Peabody, as the quotes below illustrate.

> *"No-one is discussing energy strategy in the Trust, and no one is responsible." August 2006*
>
> *"Peabody chief executive Stephen Howlett takes the lead on sustainability matters and the SHIFT feedback said that sustainability was ingrained throughout the organisation." (Inside Housing 2009)*

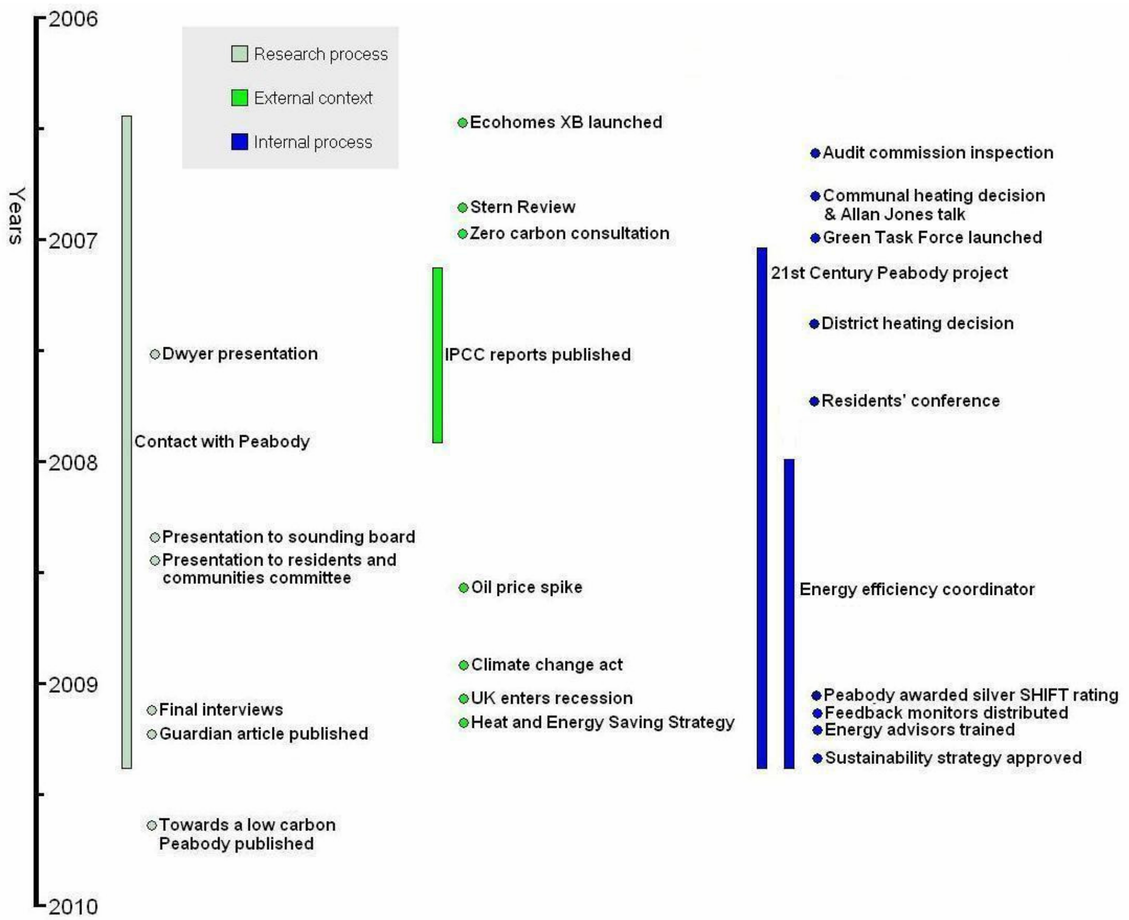

Figure 8.1 Timeline of Peabody context and actions

This shift in internal context was strongly influenced by an external shift, with the profile of climate change increasing amongst the public and businesses during the research period. From a policy perspective, 2006 culminated in the publication of the Stern Review and the UK Government's consultation on a zero-carbon standard for new housing, and was followed by the publication of IPCC reports throughout 2007. This influence was apparent amongst Peabody staff who explained their action on climate change as being "because it's in the news every week" (January 2007), or as "just the way things are going… a general zeitgeist" (February 2009). The commitment by the UK Government formalised in the Climate Change act to aim for 80% cuts in carbon emissions by 2050 (DECC 2008) and the publication of the Heat and Energy Saving Strategy (HESS) consultation (DECC 2009a) led to the question of how deep emission cuts can be achieved for existing housing rising up the agenda for Peabody.

Alongside climate change concerns, two other key external factors have been changes in fuel prices and economic conditions. The oil price spike in mid-2008, and the fuel price increases that accompanied it, brought an increased focus at Peabody on issues of fuel poverty. The start of the economic downturn, signalled by the UK economy officially entering recession in January 2009, affected loan conditions for Peabody and the economic appraisal of investments.

8.1.3 Actions undertaken

8.1.3.1 Facilitating actions

The new strategic focus on environmental issues at Peabody led to the creation of a “Green Task Force” championed by the Chief Executive in early 2007, focussing largely on environmental issues within Peabody’s business operations. Since early 2009 it has been replaced by a “Sustainability Working Group” comprising of departmental heads and chaired by the Chief Executive, with the aim of providing a forum with greater power and accountability within the organisation to drive action to meet targets in Peabody’s sustainability strategy. Following the presentation by Allan Jones in October 2006, a decision was taken to create a full-time Energy Efficiency Coordinator position within the Asset Management department, with the post being filled from January 2008.

The present research and the research conducted by Dwyer were also important facilitating actions in themselves. These studies led to a number of well-attended presentations being given to Peabody staff (by Dwyer in July 2007 and by the author in May and June 2008), alongside the extensive collaboration with the author on the present research. This engagement was reported by Peabody staff as playing a significant role in shaping internal discussion on climate change and reinstating the importance of sustainability (April 2009).

In early 2007 the 21st Century Peabody project was initiated, with the aims of creating “a vision for the organisation for the next 25 years”, and to “reinvigorate Peabody’s reputation as a leading agency on social policy issues” (Peabody Trust 2007b). As a result of the strong tie-in in scope and duration with the present research, aspects of the 21st Century project that addressed carbon reduction were studied by the researcher, leading to the report “Towards a Low Carbon Peabody” (Reeves 2009). Research findings were also publicised through a feature in the Guardian newspaper in March 2009 (Howlett 2009).

This project is one example of the increased efforts taken by Peabody during the research period to influence policy. Other actions taken include responding to two Government consultations (on the Renewable Energy Strategy and the Heat and Energy Saving Strategy) as part of the G15 group of landlords, and participating in the EEPfH Social

Housing group. Peabody has also sought to increase the profile of climate change amongst its residents by choosing it as the major theme of its 2007 residents' conference, with a former head of Friends of the Earth being invited to give the keynote speech. In 2009, Peabody was one of a small number of social landlords to be assessed using Sustainable Homes' SHIFT framework (Sustainable Homes 2009), and were positioned in the top category of landlords assessed, achieving a silver rating (Inside Housing 2009).

8.1.3.2 Technical interventions

A preliminary assessment of interventions being undertaken by Peabody in late 2006 found that most stock improvement interventions were being carried out through Peabody's DECENT and SOUND programmes, which were visiting estates in turn (respectively carrying out internal and external improvements) to bring homes up to the Decent Homes standard. The work being undertaken through these programmes that impacts upon energy efficiency includes the installation of gas central heating in around one third of Peabody homes, and the installation of cavity wall insulation, loft insulation and low u-value windows on a small number of estates (Peabody Trust 2005). These programmes were initially designed to meet but not exceed the minimum standard required, due to financial constraints (Peabody Trust 2006). The level of improvements carried out was upgraded in 2008, with the Energy Efficiency Coordinator securing grant funding to ensure that all homes would receive cavity wall insulation and loft insulation where possible.

The possible intervention of making low-energy appliances more affordable for tenants through bulk procurement was discussed by staff throughout the research period, but a delivery mechanism has yet to be established. Energy efficient light bulbs have been distributed to residents through tenant welcome packs and estate events throughout the research period. Peabody has recently started to investigate the prospects of improving the efficiency of lighting in communal areas, and through the work of the Energy Efficiency Coordinator, a trial of innovative LED lighting technologies will be taking place shortly on one estate.

Little action has been undertaken on the more extensive measures (fabric improvements, communal heating, micro-generation) explored in this research. The work that has been done is reported in section 8.7.

8.1.3.3 Behavioural interventions

In late 2006, the only behavioural intervention being carried out by Peabody was the provision of written energy efficiency advice to new tenants as part of tenant welcome packs. Tenants receiving new heating systems through Decent Homes works were not being given guidance on their efficient use, and property negotiators claimed to lack confidence in giving effective face-to-face advice to tenants. By early 2009, the latter issue had been addressed by training a number of frontline staff as energy advisors (Howlett 2009). In addition, energy monitors providing live feedback on electricity use have been made available for free to residents from late 2008 (publicised through an advertisement in the residents' newspaper). As of May 2009, 30 households had taken up the offer. In March 2009, discussions were ongoing at Peabody on the proposal of developing an online "energy hub" to provide residents with feedback, information and support to reduce carbon emissions.

8.2 Motivation

The results relating to the motivations identified for carrying out carbon reduction interventions are presented here using an adaptation of the framework introduced in 2.5.4 put forward by Bansal and Roth (2000). Once adapted so that the "Ecological Responsibility" category was broadened to "Ecological and Social Responsibility" (so that concerns about fuel poverty can also be included), this framework proved to fit well with the data.

8.2.1 Legitimation

8.2.1.1 Compliance culture

There was considerable evidence in support of the arguments put forward in chapters 2 and 3 that social landlords are strongly driven by regulation. This was reflected in what can be termed a culture of compliance, with action commonly being framed in terms of what was required by regulation, and these requirements being key drivers for the organisation.

> *"Targets... that's what [the Chief Executive's] interested in. He's, like, when's someone going to come and say 'you're breaking the law'…" February 2007*
>
> *"Where is the regulation that's going to make us do this?" July 2007*

"On a really basic level, we have to meet Decent Homes… we have to provide thermal comfort... and we don't strictly have to do any more than that." February 2009

This perspective was often coupled with a belief that strong action would be difficult to justify unless it was made compulsory, echoing the findings from the scoping interview study.

"In spite of our best efforts… unless somebody came along and said by 2020 everything has to be so and so... I think it would be really hard to justify dedicated expenditure." February 2009

Despite a strong focus on meeting minimum standards, Peabody was not compliance-driven in the sense discussed in 2.5.4, of seeking to only do the minimum demanded by regulation. Instead, there was substantial evidence of above-compliance behaviour, although this was typically only feasible when costs were relatively low. This included work carried out on behavioural interventions, developing policies on sustainability, support of the present research and employing a dedicated member of staff to work on energy issues.

8.2.1.2 Existing regulation

Decent Homes regulation was by far the strongest existing regulatory influence on Peabody (discussed in 8.1). From October 1st 2008 social landlords were obliged to provide Energy Performance Certificates (EPCs) to residents when homes were let, and Peabody was one of few social landlords to be compliant from that date. The use of SAP ratings as a Key Performance Indicator (KPI) by regulators created a motivation to show year-on-year improvements through Decent Homes measures. With regard to a more ambitious carbon reduction agenda, Peabody staff did not perceive a strong drive from Government or regulators throughout the research period.

"We're surprised they've said nothing about this so far" June 2007

"Not many people externally are pushing us to do anything about it… it would need a drastic sea-change in our KPIs, wouldn't it?" February 2009

8.2.1.3 Future regulation

Despite the lack of regulation mandating strong action to reduce stock emissions, there was a widespread expectation amongst Peabody staff throughout the research project that such regulation would be brought in soon.

“External pressures... they're not yet biting. They're evident... it's evident that they'll come.” February 2007

“It’s the right thing to do and we’re going to be made to do it anyway” June 2007

“It's going to be mandated at some point” February 2009

Research by Peabody, including support for the present research, was justified as preparation for when such regulation came in.

“Actually what's likely to happen is that at some point somebody's going to make big changes for existing buildings, and we've got to be on top of that… and unless we start thinking about it now, we'll be off the pace.” February 2007

This rationale was reflected by Peabody actively exploring the Ecohomes XB framework for assessing environmental performance from the time of its release in mid-2006 to 2008, due in part to a perception that it was likely to be a precursor of a future compulsory framework. Interest in working with Ecohomes XB had declined in early 2009, as Peabody staff felt that EPCs were more likely to be used to mandate future action.

The perception that future regulation was around the corner was typically coupled with strong concerns around its financial impact on Peabody.

“It'll be interesting to see what they do for existing buildings, because it could cripple some organisations. It's like the building regs, every time you change them, you've got to be careful that you don't just drive... just stop the economy almost...” February 2007

“How do these people think we’ll pay for it?” July 2007

“If we were forced to do it, it would have catastrophic consequences.” February 2009

This concern was alleviated by a belief that regulations would not be brought in that demanded action that was impossible to achieve, or that threatened the financial viability of social landlords.

“But then nobody can stick a piece of legislation out there that actually means that 20% of RSLs have to shut as it were.” February 2009

8.2.1.4 Sector norms

The need for efforts to combat climate change in social housing to focus on existing housing rather than new build, a point made frequently in social housing trade journals during the research period, was reported many times by Peabody staff.

> *"There's this realisation generally, well, actually, fine do all that fancy stuff for the new build... but that's only going to affect a tiny proportion of the stock, blah, blah, blah, and the real problem is with the existing stock, and what the hell are we going to do about it?" February 2009*

Relative to other organisations in the sector, there was evidence at the end of the research project that Peabody was relatively advanced in its work on climate change. Peabody was one of a small number of social landlords to be assessed using the SHIFT framework (Sustainable Homes 2009), and within the G15 group of London housing associations, Peabody was one of the few organisations (in February 2009) to have a dedicated member of staff working on sustainability issues.

8.2.2 Environmental and social responsibility

Climate change was reported as a strong motivator for action by many Peabody staff, with the increasing prominence of the issue in the media being cited as the main cause of this. Fuel poverty was not a high priority at Peabody towards the start of the research, but rose up the agenda as fuel prices increased towards 2008.

> *"I'm worried about fuel costs for this winter" June 2008*
>
> *"I guess another driver is fuel poverty, as in, it's not a statutory driver, but if fuel goes up and up and up, the cost of, there'd be a lot of our residents who'd really not be able to switch their heating on" February 2009*

These motivations were driven both with reference to the social values and poverty reduction agenda of Peabody as an organisation and through staff with environmental values driving actions through their own initiative.

> *"The other thing is, it's not an external pressure it's an internal pressure. I think there's loads of people in this organisation that are keen to get involved, and that's really a motivating factor as well." February 2007*
>
> *"As a social business we recognise the responsibility we have to protect the environment for our generation and future generations." April 2009*

8.2.3 Competitiveness

A concern for competitiveness was reflected in two goals put forward by Peabody staff for action on climate change: reducing costs and improving Peabody's reputation.

> *"What we want to do is make sure we've got an effective strategy, which is innovative, promotes a more efficient, green business… it can contribute to our financial efficiency." January 2007*

A concern for reputation was framed in terms of Peabody's recent status as a pioneer, exemplified through the BedZED development, and a desire to maintain and enhance that reputation.

> *"Given the estates that we've got, we've got the biggest opportunity, and if we can, we can achieve what is our vision of being a beacon organisation… but I think the major reason really was the wish to continue this pioneering spirit at Peabody." February 2007*

> *"Peabody in very broad terms, would like… to be seen to be at the forefront, certainly within the RSL movement, of making progressive moves towards meaningful carbon reduction within its stock." February 2009*

Financial arguments for action were rarely put forward, given the concerns about interventions not being affordable for Peabody detailed in section 8.3. When they were put forward, it was in terms of the risk that future increases in fuel costs could lead to Peabody homes having very high heating costs, making stock potentially unlettable.

> *"One way of looking at the financial case for us is, for example, if fuel prices go up severely, we might have unlettable stock – that's a financial case for this kind of investment." July 2007*

> *"I think it's also seen as a risk and it's being profiled as a higher risk for the business." February 2009*

8.3 Financial issues

The identified financial issues affecting the viability of carbon reduction interventions are presented in this section. The issues covered are the financial viability of investments

(8.3.1), barriers relating to capital costs and financial risks (8.3.2) and possible funding approaches (8.3.3).

8.3.1 Financial viability

Financial viability was an issue that was raised extensively by Peabody staff, both in terms of the organisation as a whole and for particular interventions. The issue that first and foremost Peabody needs to stay viable as a business was stressed on many occasions.

> *"Maybe we will spend two million quid on some things, but it's got to be in the context of good business sense for the organisation… we've still got to balance the books." February 2007*
>
> *"This all must fit with the business plan – with no business plan, there's no Peabody and no homes to worry about." July 2007*

The reference to balancing the books highlights that income and outgoings are not the only relevant financial issues, as the impact of investment decisions on Peabody's accounts was also seen as being significant. An example of this issue is a decision taken by Peabody to repair a communal heating system rather than replacing it with individual central heating systems, due to the substantial capital write-off the latter decision would have required.

The stock interventions explored by this research were seen as both expensive and unaffordable under current conditions if applied on a large scale in Peabody stock.

> *"There's no point externally cladding or putting in double glazing. We can't afford it and that's that." June 2007*
>
> *"Call [our current spending] £30m a year... so if we've got 15 years to do this stuff and it costs £160m, I'm going to say it's £10m a year, so we're adding a third more... it's just not feasible at all, in any way." February 2009*

As a result, the current lack of financial viability was seen as the main barrier to substantial stock refurbishment at Peabody.

> *Interviewer: "What are the big things, the main issues?"*
>
> *Interviewee 1: "Money."*
>
> *Interviewee 2: "Money."*
>
> *Interviewee 3: "Money." February 2009*

Despite the many other barriers reported in this chapter, Peabody staff felt that if the barrier of financial viability could be overcome through reduced costs, increased grant support or alternative funding mechanisms, the recommended interventions could be carried out.

Interviewer: "Let's imagine it was financially neutral for Peabody, would it be…"

Interviewee 1: "Oh yeah!"

Interviewee 2: "Why not, that's the big…"

Interviewee 1: "You know, there's nothing, there's not. Why wouldn't we then?"

February 2009

8.3.2 Capital and risk

High capital costs of refurbishment options were reported as a barrier to action on many occasions. This led to considerable discussion focussed on how capital costs for interventions such as CHP could be met, with an ESCo partnership being the main option explored. Securing capital in itself was however not problematic for Peabody, as it was made clear by Finance department staff that Peabody could borrow against the value of its stock and raise considerable funds immediately. The challenge of securing capital funding instead acted as a barrier to action because of the lack of a strong financial case for the considered interventions to counter-act the risk of making a large investment.

"Capital funding is no problem… it's just paying for it." February 2009

"I think it's the financial model that would do it… and having an acceptable risk profile." February 2009

Throughout the study, Peabody was reported as being highly risk-averse, a position due in part to a recent experience of significant exposure and a substantial cost over-run on the BedZED development. This led to funding approaches being sought "where the risk is not ours, where the risk to us is minimised" (February 2009). Partnership-working with organisations such as ESCos was put forward as a means for minimising risk.

"I think whatever you do with renewables is always going to be a partnership. I don't think we're ever going to take on that risk." February 2009

One key informant made the case that working with external businesses would be likely to reduce the financial benefits of interventions for residents, due to the greater return that they would expect on investments. As a result, it was argued that taking on some risk was necessary to ensure that residents could get a better deal in terms of fuel bills savings.

“Fuel savings are generally greater for residents where more financial risk is taken by the landlord or longer-term investment models are used.” March 2009

8.3.3 Funding approaches

Where the possibility of action to achieve deep emission cuts being mandated was discussed, Peabody staff felt that in the current context, they would have no option but to sell properties or increase rents to fund the work.

“We'll be in the same position that we've been in for Decent Homes standards, actually having to raise money suddenly, through sadly sales of properties to raise money for it.” February 2007

“I don’t think we want to consider that… but the stark consequences if we had to do it would be rent increases or lots of sales.” February 2009

Peabody staff recognised that rent increases were not possible in the current context, and whilst cautious about advocating a change that could be unpopular and detrimental to residents, saw a potential need to make the argument to policymakers that they should be permitted.

“Then there’s an argument you’d need to make as a social landlord about the ability to raise rents, or receive a grant to cover this.” July 2007

No other realisable funding options were reported as being available to Peabody. Service charge increases were legally possible, but not possible for Peabody due to the nature of their service agreements with residents. Funds from existing budgets were seen by the finance team as sufficient to cover a small deficit, but not a funding gap of the order of tens of millions of pounds.

The issue of split financial incentives discussed previously (2.7.2.2) was raised by Peabody staff, with the most common solution proposed being to share the benefits of investment with residents.

“One of the major difficulties for social landlords is that financial investment cannot be recovered through increased rents, and that reduced energy costs resulting from investment accrue to the resident, not the landlord, so there is little scope for high cost initiatives.” June 2007

When residents were asked whether increasing rents to help fund improvements could be acceptable, as part of research for the 21st Century Peabody project carried out by researchers from the Institute for Public Policy Research (IPPR), the idea was strongly rejected. This was explained by IPPR researchers as being related to the idea of a “compact” between Peabody and its residents, and Peabody not being perceived to deliver services of a sufficient quality to justify rent increases. When the idea of increasing rents to fund refurbishment was discussed in a presentation by the researcher to the Residents and Communities Committee, a resident in the meeting responded very negatively, stating that “residents would be terrified” (May 2008). It therefore appears likely that a strategy of rent increases would cause considerable resistance, even if residents are left better off overall.

Due to these problems, other funding mechanisms were being discussed by Peabody staff in 2009 which would be likely to require Government action. These included delivering improvements through an ESCo or utility companies, with a charge tied to each dwelling (rather than the householder) being levied over a decade or more to repay investment costs. This internal discussion is still ongoing, and mirrors discussion taking place more widely around the HESS consultation on how to fund more costly stock improvements (Adams 2008; Existing Homes Alliance 2009). Grant funding was also highlighted as vital by Peabody staff. This was reflected in the article published in the Guardian newspaper in March 2009, where Peabody called for funding through feed-in tariffs and the mainstreaming of grant programmes such as CESP (introduced in 2.3.1.6) to make interventions financially viable (Howlett 2009).

8.4 Knowledge, skills and internal capacity

Alongside financial issues, the other key internal resource issues identified which could influence the viability of carrying out carbon reduction interventions were the closely-related issues of staff knowledge (8.4.1), skills and internal capacity (8.4.2). As well as discussing these issues, this section reports the views of Peabody staff on addressing them through the development of external partnerships (8.4.3).

8.4.1 Staff knowledge

Staff knowledge of interventions is likely to be a relevant issue where new technologies are the focus of research, and lack of knowledge was reported on several occasions. The strategic focus on climate change at Peabody led to this being addressed through extensive information searching by staff, including attendance at events on both policy and technologies and discussion with the researcher. The relatively new focus on carbon reduction in housing led to doubts among Peabody staff on the extent to which they could trust some of the information available to them.

> *"I think there's still a massive feeling... that people just don't know what they're doing… it's sheer, unadulterated panic in the building world, and lots of consultants have set themselves up, and I don't think they know what they're on about either". February 2007*

Early in the research period, staff with responsibilities related to sustainability were commonly unaware of the research Peabody had undertaken on energy efficiency in previous years (8.1.1), or that the present research was taking place. This can be explained in part by high staff turnover at Peabody prior to the research period, and the result that "knowledge goes out of the door" (Nov 2006). During the research period, as a result of the appointment of the Energy Efficiency Coordinator and the influence of this research, internal knowledge on carbon reduction issues appeared to increase substantially.

8.4.2 Skills and internal capacity

With regard to their existing skills and capacity to work with carbon reduction technologies, Peabody staff reported a generally poor performance to date with communal heating and providing a utility service to residents.

> *"Peabody doesn't understand the management of utilities… to avoid all management issues, they sell all of the electricity generated to the grid and let Solar Century do all of the management." June 2006*

> *"We've got a very poor record in managing district heating systems, whether its understanding how to bill and meter, or understanding how to manage the piece of kit itself." February 2009*

The central issue raised when this was discussed was on the extent to which this was addressed by developing new internal capacity, forming partnerships or developing an ESCo (discussed in 8.4.3).

> *"We have to work out if we have an in-house team, or gas contractors or whatever it is that understands them, or if possible, we farm it out to a third party, but for the third party, it may not be worth their while." February 2009*

Issues of capacity were also discussed in terms of a lack of time to carry out work on energy efficiency issues. These concerns led to the creation of the Energy Efficiency Coordinator post.

8.4.3 Partnerships

In the light of the identified need for external expertise (8.4.2) and the sharing of risk (8.3.2), partnership-working with the likes of ESCos or utilities was seen as a crucial complement to the development of internal capacity by Peabody staff.

> *"The time always comes where you have to say Peabody in partnership with - because we're about providing housing." February 2009*
>
> *"It is a challenge that can only be met by powerful partnership working from social landlords, the government, utilities firms and residents themselves." (Howlett 2009)*

Work on establishing a partnership deal with a utility company has been ongoing since the Energy Efficiency Coordinator was appointed. The possibilities of using such a partnership to provide grant funding, green tariffs and social tariffs for residents in exchange for a preferred supplier arrangement for void dwellings were explored. To date no deal has been confirmed after contact with a number of utility companies, due largely to a lack of interest or capacity to deliver such an arrangement from the companies contacted.

The formation of an ESCo to assist with the management and strategy development of energy provision was recommended strongly to Peabody by the energy consultants Rickaby Thompson Associates, both prior to and during the research period. There was a lack of knowledge amongst Peabody staff on how to do this, so this issue was explored in 2006 and 2007 through meetings with potential ESCo partners. A key barrier identified was the lack of interest from potential external partners, due to the apparent lack of a strong financial case for installing CHP on Peabody estates.

> *"Sorry, but we have had the London ESCo here saying they're not interested." July 2007*
>
> *"Where are they? There's no one beating down on our door saying there's cash to be made by putting in 30 CHPs." July 2007*

As was the case with financial decisions, discussions around external partnerships were strongly influenced by a concern to minimise risk. This was largely framed in terms of whether an organisation was a "robust partner" (February 2007). This concern was motivated in part by the experience of the organisation supplying the Biomass CHP unit at BedZED going out of business. A potential risk to Peabody's reputation was also identified if it created an ESCo that delivered a poor service to residents. This concern led to the idea of developing a "G15 ESCo" in partnership with other London social landlords being explored from early 2009, so as to reduce the risks of damage to the reputation of each individual landlord that could result from problems with the supply of energy to tenants.

8.5 Organisational goals, internal processes and staff views

This section reports other relevant internal issues that affect the viability of carrying out carbon reduction interventions. These include competing organisational goals (other than carbon reduction), internal processes (such as decision making procedures) and staff views on the issues studied.

8.5.1 Organisational goals

The need for tenant satisfaction was highlighted on a number of occasions, which was reflected through concerns to avoid the potential for complaints and to prevent disruption. Issues relating to tenant acceptability are discussed in more detail in section 8.6.2, and for potential technical interventions in section 8.7.

As a heavily-regulated organisation, other relevant goals identified during the research period were typically derived from regulation. These included installing digital TV infrastructure, meeting new fire safety regulations and achieving budget savings through efficiency improvements. The conflict between minimising void times and carrying out comprehensive refurbishment in dwellings (discussed in 2.6.2) was raised as a potential barrier to action.

Conflicts between goals raise the question of how they are prioritised. It was recognised by Peabody staff early in the research period that carbon reduction was not prioritised at that time. Although in 2009 it has a much higher status, it was recognised that without a requirement to act, it would inevitably be a lower priority than goals that Peabody was forced to act upon.

> *"These things have not been prioritised." June 2007*
>
> *"Inevitably, something that we don't have to do is slipping down the agenda a bit." February 2009*

8.5.2 Internal processes

A number of common themes from the literature on organisational greening were observed at Peabody. These included the positive impact of strong support from senior management on action, and the need for middle management staff to win support for proposals from senior staff. It was recognised on many occasions that responsibility for many issues relating to energy use in Peabody stock was dispersed throughout the organisation. Effective action was hindered in part at Peabody by a “silo culture” (a term coined in 2006 by an internal working group at Peabody, referring to a lack of effective communication between departments). This was observed for action on a number of relevant issues in 2006. With regard to energy efficiency, the “silo” issue was addressed to a good degree both by the formation of the Green Task Force, which brought together staff from many parts of the organisation, and by concentrating responsibility for work on energy issues in the post of the Energy Efficiency Coordinator. The need to mainstream work on sustainability was stressed on many occasions, and action was taken to achieve this by increasingly incorporating work on sustainability in the personal performance targets of staff during the research period.

Financial constraints meant that decisions on stock investment taking place during the research period were typically subject to the criterion of being the lowest cost option, providing that an adequate level of service was provided. Resident views were standardly sought to address the latter concern, typically through consultation events.

Early on in the research period, when there was less of a strategic focus on carbon emission reduction, action was ad-hoc to a degree, being driven by motivated staff. This was exemplified by a member of staff reporting that sustainability featured as a factor in a refurbishment decision taken in 2006 “because I wanted it to be” (September 2006). A concern to make such decisions informed by a long-term strategic framework for planned stock interventions was raised by another member of staff in late 2006. Despite the greater prioritisation of action to reduce stock emissions, such a framework has not yet been established.

8.5.3 Staff views, attitudes and framing

8.5.3.1 Carbon reduction agenda

Peabody’s carbon reduction agenda over the short term and the long term was framed in a variety of different ways by Peabody staff during the research period. An agenda of pursuing deep emission cuts was not apparent at the start of the research, with the perception that Peabody stock was inefficient by its nature leading to relatively low aspirations for carbon reduction.

> *"Even a 5% improvement would be lots of tonnes of CO_2" June 2007*

In the light of wider policy discussion on achieving "zero-carbon" standards for new housing, the goal of achieving such a standard through refurbishment was suggested in 2007 by senior management as an issue for the present research to explore. Awareness of the 60% emission reduction target set by the GLA came largely from the present research rather than through the GLA itself. The view expressed by Peabody staff was that they would like to meet the target but are unable to do so due to current conditions.

> *"We are committed to doing everything we can to meet the Greater London Authority's target of cutting carbon emissions by 60% by 2025. Cutting emissions is vital if social housing communities are to be sustainable, thriving places to live and our low-income residents are to avoid increasing fuel poverty." (Howlett 2009)*

Peabody's new sustainability strategy, put forward in 2009, pledged support for long term carbon reduction targets set by the GLA for 2025 and the UK Government (for 2050). Specific targets for short term reductions were not set as Peabody does not have data available to assess progress. A target expressed in terms of carbon emissions was seen as problematic by some Peabody staff in any case, as to a significant degree, stock emissions were seen as outside of Peabody's control.

> *"That wouldn't be a fair ask of a landlord… Peabody can't control residents' emissions. It would be like asking a building society to change their customers' behaviour." June 2007*

> *"If people open the window, you've got no control over that, if people whack the heating on full then open the window... so, we're getting on to behaviour now but you still can't police that over 18,000 dwellings." February 2009*

8.5.3.2 Attitudes towards interventions

Peabody staff demonstrated a number of attitudinal responses to carbon reduction interventions, including support of their potential to reduce emissions and reduce fuel bills, and negative perceptions that could act as a barrier to action in some cases. The negative perceptions included: fear or suspicion of the unknown being given as reasons for not taking an opportunity to connect an estate to a district heating network; reluctance amongst some staff to consider trial installations of air source heat pumps; negative perceptions of district heating. Other issues raised included a perceived risk associated with installing new technologies, and scepticism about the claims made for the benefits of emerging technologies, based upon prior experience of technologies failing to meet expectations.

> *"They want to do a scheme with no heating, with no obvious heating, and I got a bit nervous". February 2007*
>
> *"A few years ago it was all microCHP, now that's not a good idea." June 2008*

The perceptions that interventions using new or emerging technologies would be complex and involve "hassle" were common amongst Peabody staff.

> *"If you connect your building to a normal network, like EDF or something, you know what's going on, but if you connect to something with a specialist service agreement, then there's all sorts of new headaches." February 2007*
>
> *"In terms of insulation though, it's fiddly, diddly, diddly. My god, just think about every window…" February 2009*

8.5.3.3 Peabody stock

The dominant framing amongst Peabody staff in 2006 was that Peabody stock is inefficient, and that there is little that can be done to improve its fabric. This led to a view that focussing on providing a low-carbon energy supply was the best action for Peabody to take.

> *"There's a limited amount we'll do to our existing stock." November 2006*
>
> *"Everyone knows this stock is conspicuously inefficient." June 2007*
>
> *"There might be no point in going mad on fabric, it might be much better saying this building's inefficient, but let's supply our own generated heat and electricity from our own generated source, and that could be better value for money." June 2008*

Towards the end of the research period, ongoing internal discussion on this issue was reflecting the view (influenced by findings from the present research) that saw fabric improvements as both viable and desirable, coupled with concerns about how effective they could be in practice.

> *"For example, our research shows that solid wall insulation is easily the most effective thing we can do to reduce home emissions." (Howlett 2009)*

"But the ones we've got are so ridiculously inefficient it seems mad to tinker around with them." February 2009

Views on insulation were also informed by a perception that solid-walled Peabody estates are currently cool in the summer, and that installing internal insulation could potentially create problems of over-heating.

8.5.3.4 Peabody's role

Peabody's role in achieving carbon emission reductions in its stock was discussed in a number of contexts, including its role in relation to action by residents, and its role in terms of broader efforts to reduce emissions in housing and in the UK in general. In the light of the HESS consultation process, discussion on this issue is still ongoing within the organisation, so the issues presented here should be understood as a snapshot of the key issues raised up to early 2009.

Regarding residents, Peabody staff commonly reported that reducing emissions was a joint responsibility, and that they should look to support residents to help them save energy. On the theme of energy provision, some Peabody staff questioned the strategic value of social landlords seeking to develop district heating provision within London. This perception was linked to a preference for Peabody to connect to existing district heating schemes rather than developing capacity itself on its own estates.

"Surely this is what local authorities should be doing, not us – we're not the appropriate mechanism for this" July 2007

Regarding micro-generation, there was support for the development of renewable energy provision on Peabody estates, but debate amongst Peabody staff on the most appropriate delivery mechanism. Among some Peabody staff there was a perception that the onus should be on utility companies to develop micro-generation capacity, rather than housing providers, as energy provision is outside of the core business of organisations like Peabody.

"I feel [the appetite is] not there… people feel we're a housing provider not an energy supplier… this is not what we specialise in." February 2009

"My vision of that is that EDF or whoever needs to be told by Government, go out and find roofs, sites for wind turbines… just go out and cover everything and they get a bit of forward funding, and we have to act as the host for all this stuff, and then we can benefit from some of it." February 2009

The strongly-preferred delivery mechanism for solar PV amongst Peabody staff is to export all electricity to the grid. This approach is attractive to Peabody as it means that there is no need to bill residents for electricity use and enables Peabody to benefit in the future from feed-in tariffs. However, it also means that residents receive no direct benefits from any installations (in terms of electricity supplied to their homes), although they could benefit indirectly if proposals for any funds raised being used for carbon reduction refurbishment are carried out.

The lack of a direct benefit for residents led some staff to question the value of installing solar PV. This response can be explained by the favoured delivery model effectively making investment in PV an investment in grid decarbonisation, with the impact in terms of reducing stock emissions being less obvious. Once framed in this way, the question of whether investing instead in off-site wind provision would be a more cost-effective intervention to reduce stock emissions was also put forward and discussed. This idea was seen as a potentially inappropriate action for a social landlord by some Peabody staff.

> *"It's a bit of an odd thing for an organisation like ours to do – why would we do it?" February 2009*

8.6 Residents

The relevant issues relating to residents affecting the viability of interventions were their priorities for improvements to their homes, their views on the acceptability of interventions and barriers to interventions on estates with leaseholders.

8.6.1 Priorities

Action on climate change was found to be a low priority amongst Peabody residents, supporting the case made in chapter 2 that this was the case for social housing tenants generally, relative to the wider UK population. Evidence for this came from interviews with tenants conducted by the IPPR as part of the 21st Century Peabody research, low engagement with discussions on climate change at the residents' conference, relatively low take-up of the offer of energy feedback monitors and the views of Peabody staff.

> *"The environment is not a priority amongst residents at present." May 2008*
>
> *"When you talk to residents at BedZED who aren't the posh ones, then the bottom line is saving money." February 2009*

The relative disinterest in achieving emission reductions relative to minimising fuel prices led to fixed-rate charging being chosen by residents for communal heating on Peabody's Coopers Road estate, bringing a likely reduction in the system's overall efficiency. Interventions that lead to an increase in fuel costs, as could be the case with a switch to electric heating systems from gas, were absolutely ruled out.

> *"Well, then that would be a no-no. You can't say to people we're going to come and do all this work, and by the way the bills are going to be higher." February 2009*

Residents were reported as being reluctant to remove gas fires from homes, despite advice by Peabody that they were inefficient, due to the role they play as a focal point and a belief amongst many residents that they are cheaper to run. If gas heating was to be removed from dwellings through a switch to communal or electric heating, the financial benefit to Peabody of no longer being required to carry out gas safety checks was felt to be unlikely to be realised, due to a perception that residents would be unwilling to give up gas cookers.

Equality in the standards available on estates was also identified as an important issue. The intervention of installing solar thermal to supply top floor flats on estates (explored by Dwyer (forthcoming) and in the present research) was judged to be "naff" and not acceptable, due largely to concerns about equality (February 2009).

For the concerns outlined above to no longer apply, Peabody staff felt that a substantially different social context would be necessary, with refurbishment at Peabody being understood as part of a national effort to refurbish UK housing.

> *Interviewee 1: "I think it helps if the Government says, right everybody, a bit of the Dunkirk spirit..."*
>
> *Interviewee 2: "That's kind of the way almost that the Government has started talking about it though, at least Ed Miliband is talking about it as a "great national refurbishment programme", and I guess you're right, if people sort of feel that everyone else is doing it and we all have to... I guess people would find it more acceptable."*
>
> *February 2009*

8.6.3 Leaseholders

A number of particular issues relating to leaseholders were identified during the research by Peabody staff, each relating to difficulties that leaseholders could create for efforts to

The lack of climate change as a motivation was emphasised by a Peabody resident in response to a presentation by the researcher in 2008:

> *"The only way you're going to save energy is if people can't afford it." May 2008*

Recent research by Peabody staff has identified security, digital TV and soundproofing as the main priorities of residents for home improvements. Improvements related to energy use were therefore rarely identified by Peabody residents.

8.6.2 Acceptability of interventions

With resident satisfaction being such an important goal for Peabody, the acceptability of interventions to residents was reported as a vitally important consideration. Issues of acceptability for particular technologies are discussed in section 8.7, whilst general themes are introduced here.

The key issue raised was that residents would need to see some significant benefits if the disruption or changed arrangements resulting from refurbishment were to be acceptable.

> *Interviewer: "So, in terms of the benefits, if you offered it to them and it was just going to cost the same as their previous boilers, you think that wouldn't be enough?"*
>
> *Interviewee 1: "No! They would be... why are we doing this? Why are we going through all this disruption? Are you mad?"*
>
> *Interviewee 2: "Because the only way you could sell it then is carbon, but people aren't interested, it's way down the pecking order."*
>
> *February 2009*

For interventions to be acceptable, Peabody staff suggested that they should result in significant reductions in running costs, or be one part of a package of improvements that includes actions that satisfy residents' priorities.

> *"If you could say to them that your fuel costs are going to be 20% less, and the old lady who lives next door is going to be able to heat her house more for less money, then there might be a feeling of community spirit, but unless that's there…" February 2009*
>
> *"It'd have to be for a whole package of things, if it was just for that, then it wouldn't really make... they wouldn't buy that." February 2009*

carry out interventions on whole estates. These issues included: an inability to make internal changes to leaseholder homes; a risk that leaseholders will not want communal systems; and a risk that leaseholders may not be willing to sell their homes if a redevelopment strategy was pursued. As no works to install communal heating or solid wall insulation took place on estates with leaseholders during the research period, it was not possible to study the impacts that these issues had in practice.

8.7 Technical interventions

8.7.1 Solid wall insulation

During the research period, solid wall insulation was only installed on a small number of dwellings on one Peabody estate (internally). Peabody has however gained experience of both internal and external cladding in the past, such as through the CARRA project, for which two post-war Peabody blocks received external cladding (Islington Council 2003). Internal insulation was seen by Peabody staff as the only viable solid wall insulation option for most estates, due to the need to preserve the appearance of external facades. It was felt that this situation would only change if a radical shift in society's goals regarding climate change impacted on the planning system.

> *"I think realistically, even if planners and conservation area officers get more relaxed about things we're not going to be wanting to or be allowed to put external insulation on all but a few of our buildings… very few. So, really we are talking about internal insulation". February 2009*
>
> *"But just imagine if there's a flipping complete crisis in 5 years, I'm sure that the planners could be told to go hang… It would take something like that, for the whole mindset to move on to that extent" February 2009*

Internal insulation was seen as being potentially problematic in terms of space reduction and disruption, complexity to install and the creation of problems with ventilation and over-heating. However, these issues were not seen to be sufficiently important in themselves to prevent its application. As discussed in 8.5.3.2, the dominant view amongst Peabody staff early on in the research was that little could be done to improve fabric on estates, a view which shifted towards the end with many staff feeling that it was worth investigating. This interest, arising through recommendations from this research and uncertainty around costs, created an impetus to carry out a pilot refurbishment to explore these issues for a typical Victorian Peabody estate. Work is currently ongoing (in May 2009) to develop such a project, with the possibilities of securing grant funding and interest from contractors appearing to be good.

> *"Would the money be there? We need to do a 19th century block and see how it could work." February 2009*

8.7.2 Communal heating

During the research period, decisions relating to communal heating on estates were made on two occasions. The need to repair a faulty communal heating system on one estate in 2006 resulted in a choice between repair of the communal system, replacement with individual boilers, or the installation of a CHP system. Despite initial interest in seizing an opportunity to install CHP, the need to satisfy residents by finding a quick solution ruled it out. The existing communal system was repaired, on the basis that this was the lowest cost option to Peabody, in spite of many residents and some Peabody maintenance staff expressing a preference for a switch to individual central heating.

On another estate, Peabody connected a small new development to an existing district heating network. This option proved effective as a carbon reduction measure, but required substantial staff time to assess questions of management of heat supply, billing and maintenance responsibilities. The connection proved to be very expensive and a connection of existing dwellings on the same estate to the network was ruled out on grounds of cost.

> *"Obviously they're shockingly expensive. The pipework you need, the primary pipework is a grand a metre or something, so..." February 2009*

A key driver for CHP provision was the GLA, who were viewed as "driving everyone" to install it. Resident perceptions of communal heating were seen as a significant barrier by Peabody staff, both because of its poor track record in the past and the potential for breakdowns affecting whole estates to damage Peabody's reputation with residents.

> *"If one heating systems breaks you have one resident to deal with, if a district heating system breaks you've got a whole estate full of people and their MP..." September 2006*
>
> *"So, there's that but then replacing individual boilers with district heating has a massive psychological issue attached to it. Again the Dunkirk spirit would have to come back." February 2009*

There was uncertainty about the financial case for investment in CHP. A number of advisors informed Peabody that it would lead to marginal fuel bill savings at best, although Peabody staff were also aware of evidence that some schemes had achieved significant cost savings for residents.

> *"I think a lot of people we've spoken to at the G15, they seem to think that with district heating or CHP, there's a very marginal fuel saving for residents, whereas it can be significant." February 2009*

It was also recognised that for CHP, the financial case for investment would be much more complex than a simple capital cost and payback argument that might apply with some technologies. It was felt that this would make it potentially challenging to sell the idea to the finance department and senior management.

When asked in the final interview whether a substantial number of district heating and CHP installations could be carried out over coming decades for Peabody stock, there were strong doubts amongst the interviewees that it would ever happen. However, as was the case for fabric improvements, there was interest at the end of the research period in getting experience of converting an estate to communal heating, and research on this possibility is currently ongoing.

8.7.3 Solar PV and solar thermal

At present Peabody has solar PV installed at BedZED, on two of its Kings Cross estates, and at its West Silvertown estate. There was support for carrying out more installations if it could be cost-neutral or profitable, and there was hope amongst Peabody staff that the feed-in tariffs pledged by Government would be set at a level that would enable this to be the case. There is no solar thermal installed on Peabody stock and this has been given little consideration to date by Peabody staff. Although they ruled out installing it to supply top floor flats on the grounds of inequity, they were interested in the possibility of installing it on houses and bungalows. This may also be explored in the future, provided that a favourable financial case can be put forward.

8.7.4 Electric heating technologies

Peabody has no heat pumps installed at present in their stock. It was felt by Peabody staff that the scope for installing ground source heat pumps was limited, but that there was potential to use air source heat pumps. This idea encountered the barrier of staff being reluctant to experiment with this new technology when the idea was raised by the Energy

Efficiency Coordinator. Switching homes to conventional electric heating in a context of grid decarbonisation was seen as potentially very beneficial by staff in the final interview due to the simplicity of installation and reduced spending on maintenance. However, if installing electric heating would result in increased fuel costs for residents, as would appear likely, it was deemed to be out of the question.

8.8 Summary

Through participant observation with Peabody, a number of significant issues affecting the viability of carrying out carbon reduction interventions have been identified. Peabody has been shown to have increased its prioritisation of work to reduce stock emissions during the research period, but its staff feel that substantial action is not possible in the current context due to the increased expenditure required. With cost being the key barrier identified, this has led to an internal focus on exploring and developing models for making stock refurbishment financially viable, and attempting to influence policymakers to change external conditions. Resident satisfaction was also identified as a key issue, with residents showing little interest in reducing emissions, creating a need for interventions to bring significant benefits for any disruption to be seen as worthwhile.

Peabody was found to be driven both by the need to comply with regulatory standards and ethical motivations for carrying out refurbishment. Regulation and a clear framework for action from Government appeared to be necessary to drive more substantial action to reduce stock emissions, both to ensure the prioritisation of action relative to other goals and to overcome the barrier of a lack of resident support constraining the action Peabody is willing to take.

A lack of internal capacity for managing new technologies was also shown to be a significant issue. The process of developing internal skills or partnerships with external organisations to address this was to some degree contested, due to some staff feeling that energy provision was a departure from Peabody's core business. An internal discussion on how Peabody should look to contribute to renewable energy provision is ongoing. There is support in principle amongst staff for installing micro-generation technologies, but a requirement for changed market conditions to make investment financially viable. Discussion is also ongoing on whether delivery should largely be the responsibility of Peabody, or whether utility companies should play a leading role.

Chapter 9: Discussion

This chapter summarises the findings reported in chapters 6, 7 and 8, and relates them back to the literature discussed in chapter 2 and the scoping interview study discussed in chapter 3. The discussion is structured with reference to the three research objectives of this thesis given in 1.1: section 9.1 discusses findings relating to carbon emission reductions; section 9.2 discusses contextual issues identified; section 9.3 discusses the financial implications of refurbishment. The research questions set out in chapter 3 are each addressed in sections 9.1 to 9.3. Some implications from this research for policymakers are then proposed (9.4).

9.1 Carbon emission reductions

This study sought to address three questions relating to carbon emission reductions:

- Can Peabody achieve deep cuts in CO_2 emissions from its existing homes in the period up to 2030?
- What technical interventions are required to achieve deep emission cuts in Peabody stock?
- Can Peabody meet the Greater London Authority's (GLA's) carbon reduction target for 2025 or achieve zero net carbon emissions across its stock by 2030?

This section discusses the findings relating to these questions in terms of the achievement of deep cuts and meeting the GLA target (9.1.1) and meeting a zero-carbon target (9.1.2).

9.1.1 Deep emission cuts and the GLA target

The PEM study found that both deep emission cuts in general and the GLA target in particular could be achieved through a combination of technical interventions, a favourable context and changes in the financial implications of refurbishment. A key finding is that even if Peabody were to use every technology considered to the greatest possible extent on its stock, there is no guarantee that this would lead to the GLA target being met. Significant changes in external factors are also necessary (discussed in 9.3), with two critical factors being constrained resident demand for energy and the availability of low carbon energy (grid electricity or district heating). As a result, of the four scenarios modelled, the target can only be met with a good degree of confidence in the Sustainable Development and Power Down scenarios.

The extent of refurbishment required in these two successful scenarios to meet the GLA target depends on the emission reductions already achieved due to beneficial external factors. The most cost-effective approaches involve insulating all solid-walled estates (with residents being decanted on estates in conservation areas to achieve this), connecting up to 25% of estates to district heating networks and installing communal biomass boilers on suitable estates. If the burden to reduce emissions falls more on physical improvements to Peabody stock, or if reductions of the order of 80-90% are pursued, extensive use of less cost-effective measures such as solar PV would also be necessary.

These findings are in strong agreement with the previous research on achieving deep emission cuts in UK housing reported in 2.4, where an extensive deployment of technical measures coupled with an assumed supportive context has been found to be necessary to meet long-term CO_2 reduction targets (BRE 2005; Boardman et al. 2005a; Boardman 2007; Natarajan and Levermore 2007; Energy Saving Trust 2008; WWF 2008).

In terms of the effectiveness of particular technical interventions, the Peabody Energy Model (PEM) study found that fabric improvements, communal heating and micro-generation could each have a significant impact. Solid wall insulation and solar PV have the greatest potential to reduce total stock emissions, although the latter is at present considerably less cost-effective. As discussed in 5.5.6, the findings related to solid wall insulation should however be treated with some caution as the possible impacts of the measure in terms of potentially leading to over-heating have not been taken into account.

Assumptions of declining carbon grid intensity in future years led to technologies generating electricity (CHP and solar PV) having a less beneficial impact and technologies using electricity (electric heating and heat pumps) having lower associated emissions. This issue has been increasingly acknowledged in publications addressing domestic carbon emissions, such as (DECC 2009a). The finding in the present research that by 2030, gas boilers could become a better option than gas-fired CHP has been highlighted in BERR's Renewable Energy Strategy (BERR, 2008a), and the issue that electric heating could be a lower carbon option than gas heating has been raised by the Committee on Climate Change (CCC, 2008). Gas-fired CHP was explored due to the recommendations put forward to install the technology on Peabody estates in prior research (RTA 2003), so the finding that it has only a minor impact in terms of emission reductions when grid decarbonisation is achieved implies that Peabody should reconsider whether installing CHP on estates is an effective carbon reduction measure. This study did not consider the possible impacts of emerging technologies or efficiency improvements in existing technologies, so the findings should be viewed as relatively conservative from the perspective of what can be achieved through technological improvements.

Where the impact of conservation area constraints was considered, it was found that removing this constraint could lead to further emission reductions of up to 8% (half through the use of external solid wall insulation, and half through installations of solar PV). Much of this benefit could however be achieved without altering the external appearance of heritage dwellings, by temporarily rehousing residents so internal insulation can be installed, and by installing solar PV on roof space that is not visible from public areas. The model results did not provide evidence that the high proportion of Peabody homes in conservation areas makes it challenging to achieve deep emission cuts. On the contrary, where distinct stock types were considered, the results identified that after cost-effective carbon reduction measures have been carried out, deeper emission cuts are achievable from Peabody's older, less efficient stock, due the greater scope for improvements.

Whilst the conclusion that greater cuts can be achieved in older stock appears fairly intuitive, prior research has not emphasised the impact this has on the emission cuts that should be sought from distinct stock types. Pilot refurbishments of existing pre-war dwellings have instead used Government targets of 60% or 80% emission cuts to judge effectiveness (EST 2004b; Green Building Press 2008; Green Building Press 2009). The implication for landlords such as Peabody that manage older stock is that they may need to achieve greater emission cuts to compensate for the lower cuts achievable in more modern stock (which is more typical of the general age profile of the social housing sector).

Conversely, as baseline emissions on Peabody estates appear to be below the UK average (6.1.1), as is likely to be the case for other social housing (Brandon and Lewis 1999; BRE 2006d), it could also be argued on the grounds of equity that greater emission cuts should be achieved in other housing sectors. This theme is likely to lead to increased discussion in future years as policies to stimulate deep emission cuts from existing housing are increasingly developed.

9.1.2 Zero-carbon

In this thesis, an estate has been described as "zero-carbon" if its net on-site carbon emissions are zero or less. Net emissions are the total carbon emissions arising from on-site energy use subtracted by any emissions saved due to on-site electricity generation.

For the whole Peabody stock to be zero-carbon by 2030, radical change in the generation of grid electricity is necessary, so that it is produced entirely from zero-carbon sources by that date. Given this extremely challenging requirement, there is no package of measures that can be recommended to Peabody to achieve zero stock carbon emissions through its own efforts. The technical viability of developing a zero-carbon grid is uncertain, although the Centre for Alternative Technology has outlined a broad approach for achieving this in the UK by 2027 (CAT 2007), and a close to zero-carbon grid by 2030 has been recently called for by the UK's Committee on Climate Change (CCC 2008). The political viability of this goal is much more doubtful, as achieving this would require radical changes in the perceived level of action required to mitigate climate change on the part of both the public and Government. The scale of the effort required to develop a zero-carbon grid in the UK by 2030 is substantial, going greatly beyond the action necessary to meet the EU target of 15% of final energy demand in the UK being met by renewables by 2020 (BERR 2008a). This more modest target was reported recently as being likely to be missed by a wide margin, based upon current and projected policies (Cambridge Econometrics 2008).

If grid electricity is produced without carbon emissions, no direct emissions due to energy use on Peabody estates can be offset through onsite generation. As a result, for Peabody homes to achieve zero-carbon status, no natural gas can be used to provide energy on its estates, either for boilers or communal heating. In this context, Peabody stock could technically achieve zero-carbon status simply by being powered entirely by electricity. However, in practice, substantial demand reduction is likely to be required to make a zero-carbon UK viable (CAT 2007). To play its part in this demand reduction, it is likely that Peabody stock would need a comprehensive programme of solid wall insulation and installations of solar thermal and solar PV where viable. Electricity could be used for supplying heat more efficiently by the installation of both ground and air source heat pumps where appropriate. Any communal heating systems would need to be fuelled entirely by biofuels, such as wood or biogas. This could be problematic, as the availability of biofuels is likely to be insufficient to provide for all heating needs in London (Building Design 2007) and the use of biofuels may be limited by concerns about particulate pollution (BERR 2008a). There is therefore a risk that the development of communal infrastructure, although effective at reducing emissions over the lifetime of the first communal boilers installed, may not be beneficial for achieving zero net carbon emissions across Peabody stock.

These findings could not be contrasted to other research on the achievement of zero net carbon emissions in existing housing developments as no studies that investigate this are known to the author. Evidence that existing homes with gas boilers can currently achieve zero net emissions through onsite generation (McCarthy 2009) does however indicate that a zero-carbon grid is not necessarily required for all dwelling types.

9.2 Contextual issues

The research question relating to contextual issues was:

- What impact do contextual factors — external and internal to Peabody — have on the emission reductions that can be achieved?

Findings from both the PEM study and the participant observation study are presented in this section. These relate to: grid decarbonisation (9.2.1), demand reduction (9.2.2), motivations for action (9.2.3), the acceptability and take-up of interventions (9.2.4) and internal organisational issues (9.2.5).

9.2.1 Grid decarbonisation

The PEM study found that a degree of grid decarbonisation was a necessity if the GLA target was to be achieved, and total grid decarbonisation was required to meet a zero-carbon target. The 50% decarbonisation by 2025 assumed in the SD and PD scenarios that allow the GLA target to be met is of a similar order to the changes called for in the GLA's Climate Change Action Plan to allow the target to be achieved (GLA 2007). The extent of refurbishment required was found to depend significantly on the level of grid decarbonisation. A pathway towards a 90% reduction in the carbon emissions associated with grid electricity, as advocated by the Committee on Climate Change (2008) would enable fabric improvements alone to be sufficient for Peabody stock in the Power Down scenario (Table 6.4).

9.2.2 Demand reduction

Levels of energy demand were the second key external factor identified in the PEM study affecting the emission reductions that can be achieved. The two successful scenarios assumed reductions in demand of up to 20% by 2030. Where changes in demand up to 2025 that would allow the GLA target to be met were considered, the PEM study found that reductions of beyond 35% were required for the Base approach and reductions of between 20% and 28% for the Fabric approach. For the Renewables approach, a 15% reduction was required for KLO and BD, whilst a 1% increase was possible for SD and PD. These figures can be compared to an estimated 33% potential saving in domestic energy use achievable without radical changes in householder circumstances (Sonderegger 1978) and reductions of 15%-25% achievable through feedback on energy use (Darby 2006). This comparison makes the reductions in demand required to meet the GLA target through Peabody's current planned refurbishment approach appear very challenging. The Fabric refurbishment strategy appears to potentially be sufficient if supported by strong efforts to reduce demand, whilst a strategy close to the Renewables approach is a necessity if demand reduction is not achieved.

Either a reduction or stabilisation of energy demand could be challenging to achieve in practice given the trend in recent years for demand for electricity to increase (NAO 2008), driven by increased use of energy for home entertainment (EST 2007d). Such changes should not be ruled out in principle, although they would be likely to require significant changes in the social practices affecting energy use demand (Shove 2009).

9.2.3 Motivations

The findings from the participant observation study were in strong agreement with those from the scoping interview study on the issue of motivations to reduce emissions. The key issue identified was that strong external drivers for the achievement of deep emission cuts did not exist at present, and such drivers, alongside policy changes, will be required to meet this goal and ensure that the required refurbishment can be resourced. This finding is due to the great importance placed by Peabody (and other social landlord staff) on compliance with regulation, and the resultant need to mandate action to reduce carbon emissions, so that this issue is given sufficient priority relative to other externally mandated goals. The policy implications of this are discussed in 9.4.

Of the other motivations identified at Peabody, a concern to improve Peabody's reputation by taking a lead within the social housing sector on this issue was a key driver. As a result, Peabody closely fits the description put forward by Egmond et al. (2006) of "early market actors", which are housing associations taking proactive action to improve stock energy efficiency. The description given by Egmond et al. fits well in terms of Peabody being vision-driven, and using long-term strategic considerations in the framing of decisions, rather than short-term pragmatic considerations alone. Peabody only differs from the characterisation provided of early-market actors in terms of their relatively low willingness to take on risk, creating the need for funding frameworks to be made available which allow levels of risk to be minimised.

A further motivation identified that relates to a competitive case for stock refurbishment was the potential risk that homes may become impossible to let if future fuel price increases lead to residents having prohibitively high fuel bills. This was seen as a potentially serious issue both by Peabody staff and interviewees in the scoping interview study, and could provide motivation to both insulate homes to reduce space heating needs or to invest in micro-generation to provide increased security of supply.

Ethical considerations also played a significant role in motivating action. In Peabody's case these included the social values of the organisation itself, the motivation to reduce carbon emissions displayed by individual members of staff and the related ethical concern to prevent fuel poverty. As a result, the theoretical framework for motivations for corporate greening put forward by Bansal and Roth (2000), was extended by broadening the "ecological responsibility" motivation to "ecological and social responsibility", thus including other ethical concerns (specifically, concerns about fuel poverty).

9.2.4 Acceptability and take-up of interventions

The acceptability of interventions for Peabody's residents was identified as a key requirement by Peabody staff and as a result could pose a significant barrier to action. Reducing carbon emissions was identified as a low priority amongst Peabody tenants, in agreement with previous research on the views of social housing residents (Walker and Oseland 1997). The potential disruption and inconvenience resulting from refurbishment was seen as a barrier which would require residents to perceive tangible benefits, in particular in terms of reduced fuel bills, if it was to be overcome.

Peabody staff also felt that if action could be framed in terms of a UK-wide effort to reduce emissions from housing, then residents would be more likely to be supportive. This can be understood as an example of the common argument that Government needs to provide leadership and a supportive context for individuals to feel that environmental behaviour is having a meaningful impact (SDC 2006b). Discussion on existing housing refurbishment is increasingly moving in that direction, with a new campaign being launched in 2009 calling for “a Great British Refurb” (Great British Refurb 2009) and recent research conducted for the Government indicating support for this agenda (DECC 2009d).

Equality between households was identified as a relevant issue by Peabody staff, with interventions being seen as undesirable is they could result in neighbouring householders perceiving a significant difference in the quality of their homes. This concern resulted in some possible measures being ruled out by Peabody staff, and created an interest in mechanisms to spread the costs and benefits of refurbishment across whole Peabody estates or its whole stock. Developing an ESCo that supplied energy to all Peabody homes was a possible delivery method put forward.

The acceptability of changing the external appearance of dwellings was another issue discussed. External insulation was not seen as viable for stock that was listed or in conservation areas, unless local authority planning policy was radically changed. Other interventions, including micro-generation, were seen as likely to be viable to some degree, despite planning constraints, due to the precedent of installations on existing heritage buildings. With regard to particular interventions, negative perceptions based upon the poor past experiences of both staff and residents were seen as hindering the installation of communal heating. Staff were also concerned that communal heating could be negatively perceived by residents as providing less control than individual boilers, despite the fact that this needn’t be the case. This theme was also identified in the literature review (2.7.3), and overcoming this barrier is likely to require both residents and staff gaining positive experiences of communal heating through a diffusion of the technology over future years.

Questions were raised by some Peabody staff about whether it was Peabody’s role to install micro-generation technologies on its stock to help reduce UK emissions, or whether this was the responsibility of utility companies. A related issue was the concern that micro-generation was not the most cost-effective way to develop the supply of renewable electricity. This emerging issue is part of the much broader question of what the most desirable strategies for mitigating climate change are for the UK as a whole. If a significant application of micro-generation is necessary to achieve targets on-site for existing housing, concerns about cost-effectiveness could lead to a preference for achieving further reductions off-site, through increased decarbonisation of the grid.

Chapter 2 identified that the take-up of interventions by Peabody fits well with the process of diffusion of innovations discussed by Rogers (2003). Table 9.1 summarises the issues identified affecting their take-up that are discussed in this chapter that relate to the 5 key factors put forward by Rogers as affecting diffusion rates.

Attribute	Issues identified
Relative advantage	Prohibitive costs are key barrier. Negative perceptions of communal heating. Doubts about effectiveness of fabric improvements (viability of ventilation and risk of over-heating).
Compatibility	For residents, no strong desire to refurbish homes. For Peabody, stock refurbishment fits well with social values (addressing fuel poverty and climate change) and staff values.
Complexity	For Peabody, many technologies require new ways of working, leading to resistance to change. Solid wall insulation and district heating networks perceived as complex to install.
Trialability	Strong for all technologies. Peabody is seeking to trial estate-wide refurbishment of Victorian stock with solid wall insulation and communal heating following this research.
Observability	Existing housing refurbishments and low-carbon technology installations are highly publicised through organisations like the Energy Saving Trust. Peabody staff have typically investigated existing exemplars where possible.

Table 9.1 Properties of interventions in terms of Diffusion Theory

The interventions under consideration perform strongly in terms of trialability and observability, but relatively weakly in terms of relative advantage, compatibility and complexity. These conditions indicate why pilot projects are currently viable, but the mainstreaming of action has not yet taken place.

9.2.5 Internal issues

The key internal issues identified at Peabody related to internal resources, and in particular, Peabody's capacity and capabilities for working with new technologies. Such issues were anticipated, given the early stage of the diffusion of low-carbon refurbishment in the UK (discussed in 2.5.3). The new skills required for actions such as billing residents or developing communal heating led to a preference to work in partnership with external organisations to deliver carbon reduction interventions. This method was seen as important to provide support in terms of developing internal expertise, sharing the financial risks of investment and reducing any reputational risks that could result from service problems with a Peabody-branded service. These concerns and possible solutions have been explored extensively in literature on refurbishment of social housing (EST 2007a; EST 2006; London Energy Partnership 2007). The low take-up to date appears to be due principally to the high costs associated with the interventions concerned, rather than to an inability to develop internal organisational resources.

9.3 Financial implications

The research questions relating to the financial implications of stock refurbishment are:

- What are the cost implications of stock refurbishment for Peabody and how can these costs be met?
- Can action by Peabody be justified financially in terms of: Peabody being better off overall? Peabody and its residents being better off overall? Society being better off overall?
- What are the impacts on residents' fuel bills and on the extent of fuel poverty arising from interventions to reduce stock carbon emissions?

Sections 9.3.1 and 9.3.2 address the two parts of the first question. The second question is discussed in 9.3.3 and section 9.3.4 addresses the third.

9.3.1 Cost implications for Peabody

The results of the PEM study imply that interventions beyond those currently planned by Peabody are required to achieve deep emission cuts in Peabody's existing stock, and additional spending up to 2030 is required. To achieve the GLA target the level of increased spending varies significantly (from £60m to £240m) depending on the extent to which external factors secure emission reductions and the level of confidence with which the target is met. This expenditure would represent a radical change in the current approach to refurbishment for Peabody, as it would for other social landlords with similar stock. The participant observation study found that additional spending of the order of tens of millions of pounds was unlikely to be affordable for Peabody within its existing budgets. The increased spending required was therefore identified as the key barrier to achieving deep emission cuts, in agreement with one of the main findings of the scoping interview study.

The front-loading of expenditure and difficulties in raising capital were not identified as a significant issue for Peabody, as sufficient capital could be raised through loans secured on their existing stock. This capability to borrow will vary between social landlords and may present a significant barrier for other housing associations or for local authorities managing housing (as the latter are likely to have less freedom to borrow). However, the key barriers identified related to the lack of a financial model to help make investment cost-neutral and reduce the risks involved, as opposed to securing capital itself (discussed in 9.3.2).

In terms of capital costs, the PEM study calculated the average costs of carrying out all interventions as approximately £24,500 for treated homes, or an average of £15,400 across the entire stock (including untreated homes). Contrasting these figures to existing literature reveals considerable uncertainty on the capital costs involved in carrying out low-carbon refurbishments, which is mainly due to the small quantity of refurbishments carried out to date and the uncertainty about future changes in costs (Hinnells 2005; Killip 2008). Of the few estimates available at present, the Existing Homes Alliance has put forward an average cost of £20,000 for low-carbon retrofitting (Existing Homes Alliance 2009), and the consultancy Energy for Sustainable Development (ESD) has estimated a cost of £25,000 to £30,000 to achieve a 60% emission reduction for an average UK dwelling (T-Zero 2007). The Hyde housing association refurbishment of a Victorian terrace was reported by Peabody staff as costing £40,000. Boardman (2007) estimated the funding required to carry out low-carbon refurbishments as £15,000 on average, and suggested a lower cost of treating homes in a Low Carbon Zone as £7,500 (including solar hot water, solid wall insulation, a connection to a district heating connection and other repairs). Peabody experience to date implies that the costs suggested by Boardman are a significant underestimate, and are likely to be up to three times greater in practice. Overall, the figures used in this study are towards the middle of the range identified in prior research and through whole-house refurbishments that have been carried out to date. When the findings from the present research on refurbishment costs were put to Peabody staff in the participant observation study, several staff felt that the cost estimates for the work involved were still lower than their expectations.

In terms of individual measures, the analysis of the cost-effectiveness with which each measure reduced emissions showed that each measure required expenditure that would not be recouped over its lifetime through fuel bill savings. The most cost-effective measures were solid-wall insulation, connection to district heating networks and installation of biomass boilers. Measures such as solar PV and gas-fired CHP were much less cost-effective, although they became more so in scenarios where they were given significant financial support by Government. Evidence from the participant observation study that residents would expect greater financial benefits from any disruptive refurbishment than those assumed in the PEM study implies that the financial case for communal heating in particular may be worse than was presented in chapters 6 and 7.

The ranking of measures is consistent with existing comparisons of the cost-effectiveness of technical interventions (Defra 2007a; Croxford and Scott 2006). The findings differ from the assumptions in some existing studies that solid wall insulation provides a pay back over its lifetime (such as Defra (2007a) and Adams (2008)), in that the Fabric package incorporating solid wall insulation does not have a positive NPV. This can be explained by the extra works typically required (for example, to install double glazing or extractor fans) and the relatively high costs based upon Peabody experience to date. If fabric improvements are not financially attractive in practice, this is likely to seriously undermine funding mechanisms based upon the principle that fuel bill savings will exceed financing costs (such as those reviewed by the Existing Homes Alliance (2009)).

9.3.2 Funding approaches

The identification of a significant funding gap to achieve deep emission cuts raises the question of how this gap could be bridged. Possible sources are the tenants themselves (through increased rents or other charges), the general public (through increased Government grants or charges administered by utility companies), through the sale of social housing stock, or through reducing spending on other services and operations. Each of these approaches is problematic, but some combination of them is likely to be necessary to fund deep emission cuts in social housing.

The implications of increasing rents or selling homes to fund refurbishment to meet the GLA target were explored. Depending on the extent of refurbishment required and grant availability, annual rent increases in the range of 0.2% to 0.9% per annum (leading to an overall increase of between 4% and 19% by 2030) would be required. Putting this rent increase figure into context, the National Housing Federation, a body which represents English housing associations, has called for Government legislation on rent increases to be changed, permitting increases of 1% a year beyond inflation rather than the current 0.5% a year (NHF 2007). This further 0.5% increase would enable the Good Confidence approach to be funded in the Power Down scenario. However, it should be noted that this increase was called for as it was seen as necessary to fund further construction of new housing, rather than to fund carbon reduction refurbishment (ibid). There would therefore be competing demands on any increased rental income, and a potential need to increase rents beyond the figures given here if both goals were to be met. A strategy based on rent increases would also potentially conflict with the core goal of social landlords of providing affordable housing.

Rent increases could be a more viable funding method in Peabody's case, as existing rents are lower than average social rents in London, and some way below Government-set target rents for Peabody stock. If permitted by Government, faster convergence towards target rents at Peabody could generate sufficient extra income to fund the more-extensive refurbishment options considered in this research. However, the evidence from the participant observation study which identified residents' strong resistance to rent increases (even if they are left better off overall due to fuel bill savings) indicates that such a strategy is likely to be extremely challenging to carry out in practice.

If this option remains unavailable to Peabody and without the provision of further grant funding, it is likely that sales of stock would be required. In Peabody's case this would necessitate the disposal of between 210 and 730 homes (up to 4% of Peabody stock). These figures can be contrasted to Peabody's current disposals programme, designed to provide funding to meet the Decent Homes standard, which involves sales of approximately 600 homes by 2010. Due to the reduction in the availability of social housing that this strategy would bring about, it is doubtful that social landlords would choose to pursue this funding strategy unless action to refurbish existing housing was mandated by Government.

Peabody staff identified the inability to benefit from the savings that result from stock investment as a barrier to funding refurbishment, a point already made many times in recent years in literature discussing social housing refurbishment (ten Donkelaar 2007; Housing Corporation 2008a; Housing Forum 2009). The assumption that a changed mechanism alone would be sufficient has been questioned by the findings from this research that residents would be worse off overall if rent increases were used to fund refurbishment (9.3.3). There was however, ongoing discussion at Peabody about delivery mechanisms that could enable investment costs to be recouped to some degree from householders. Peabody staff suggested a particular mechanism for recouping investment costs proposed by the UK Green Building Council of utility companies administering a charge tied to a dwelling (rather than particular householders). Recent discussion on Government policies for making low-carbon refurbishment financially viable has also stressed the need for interventions to have low upfront costs, and a variety of approaches for achieving this (discussed further in 9.4.1) have been put forward (Adams 2008; Existing Homes Alliance 2009).

Increased grant funding is the main remaining funding approach if significant stock sales or increased rents or charges are not seen as an acceptable funding method for social housing. Boardman (2007) advocated the use of grant funding to completely fund stock refurbishment for social landlords. In a report on the financing of extensive carbon reduction refurbishment, the Existing Homes Alliance has proposed that for social landlords, 50% grant funding supplemented by low-cost loans should be sufficient to incentivise investment (Existing Homes Alliance 2009). Given the significant increase in expenditure identified in this research, it certainly appears that meeting the majority of costs through external funding in some form will be a requirement if stock sales and rent increases are to be avoided or minimised.

The financial risk involved in stock investment was highlighted by Peabody staff, and created a desire for investment mechanisms to be developed that would enable other parties to take on risk. In addition, the need for effective funding models to be created which would attract external investors was also identified. Use of CHP was reported as being held back by the lack of interest from investors due to the low profits available on investment. An example of a framework put forward that addresses these issues is the proposed feed-in tariff system recommended by the Renewable Energy Association (REA 2009). This would largely eliminate perceived risk, due to Government guarantees of future income streams, and the greatly increased funding levels would make investment profitable for commercial investors.

In an interview conducted for the scoping interview study, one respondent argued strongly that upgrading all existing social housing stock was not affordable, and that the viability of funding this work needs to be identified before targets for improvements are set (3.3.3). The research findings have supported this sceptical attitude, as in Peabody's case significant costs would need to be met through external funding (unless stock is to be sold or rents increased). The question of whether Government itself is willing to invest the billions of pounds identified in other studies as necessary to stimulate widespread existing housing refurbishment (Boardman 2007; WWF 2008; Existing Homes Alliance 2009) remains unanswered at present.

9.3.3 Financial case for work

9.3.3.1 Peabody and its residents

For the lowest cost approaches that meet the 2025 target with a good degree of confidence, the NPV for Peabody is minus £77 million for the Sustainable Development scenario, and minus £54 million for Power Down. Although there is significant uncertainty attached to cost estimates for refurbishment approaches, the conclusion that the NPV is negative in each case appears to be robust. If no grant funding is assumed, these figures increase in magnitude to minus £105million for the SD scenario and minus £91 million for the PD scenario.

Each approach considered also has a negative NPV where Peabody and its residents are considered as a whole. This indicates that even where the reduction in fuel bills achieved by refurbishment is taken into account, Peabody and its residents are financially worse off overall when each approach is carried out. As a result neither a business case nor a social case (as defined in 5.10.2) for achieving deep emission cuts exists. These findings are in general agreement with the research discussed in chapter 2 on the cost-effectiveness of more expensive or disruptive carbon reduction measures. Research to date is extended in the present thesis by considering the impacts of changed contextual factors and changing levels of financial support, which in each scenario still do not make any of the considered interventions cost-effective.

The use of NPV rather than simple payback for financial assessment necessarily creates a more negative picture of financial viability, as greater weight is put upon upfront costs rather than longer term savings. As a result, even if solid wall insulation can achieve a simple payback over 20 years as some studies have reported (Defra 2007a; Adams 2008), it is likely to have a negative NPV. As discounting will be used in practice by individuals and businesses when making investments (Ryan 2007), this approach is likely to better reflect financial viability than an assessment of simple payback.

9.3.3.2 Shadow Price of Carbon

The impact of attributing a value to emission reductions was explored using Defra's Shadow Price of Carbon (SPC), which measures the marginal damage caused by the emission of an extra tonne of CO_2 (Defra 2007f). The Government recommended figure of £25 per tonne of CO_2 (in 2007) was used, increasing by 2% a year in real terms. This approach and the resultant relatively low carbon price has been criticised as not being useful for policy appraisal due to the apparent circular nature of its definition (Friends of the Earth 2008), whereby the SPC value is dependent upon an assumed global carbon emissions trajectory, but the level it is set at and its use in investment appraisal significantly affects this outcome (ibid).

The impact of the SPC on NPV calculations was to increase the NPV and Peabody NPV of more substantial approaches by up to £5 million. Both NPV and Peabody NPV were still negative for every approach in every scenario where it was considered, even where the maximum recommend value for SPC identified in literature was used. It therefore did not create a case for refurbishment beyond Peabody's current planned approach.

One interpretation of these results could be that emission reductions on Peabody estates, and by extension in similar social housing, are simply not cost effective and that the carbon reduction burden should be met in other sectors, where consideration of the SPC results in more cost-effective projects. This conclusion should be treated with caution however, given the common claim that housing may be one of the least challenging sectors of the economy in which to achieve emission reductions (Bows et al. 2006). If that claim is correct, then it appears that use of the SPC within the range currently advocated by economists may not lead to decisions to invest in carbon reduction measures that are required to meet climate change targets. If that is indeed the case, the criticisms made of the SPC by Friends of the Earth (2008) appear to have some validity.

9.3.4 Resident fuel bills and fuel poverty

Fuel bills in 2008 on Peabody estates are estimated as below the UK average for all estates, with fuel poverty existing in 3% of Peabody households. This estimate is close to an estimate of 4% of social landlord households being in fuel poverty from research conducted in 2007, supporting the method used as producing reasonably accurate results (EEPfH 2007). The findings from the PEM study indicate an increase in fuel bill levels, and consequently the prevalence of fuel poverty, due to the assumption that fuel costs increase in real terms to 2030 for all scenarios. If Peabody's planned approach to refurbishment is carried out, fuel poverty levels increase to around 6% by 2030 for all scenarios except Breaking Down, where the assumed high fuel costs lead to over 25% of Peabody households living in fuel poverty.

Applying solid wall insulation on Peabody estates (either externally, or internally in void dwellings for estates in conservation areas) is the most effective measure for combating fuel poverty. If fuel prices remain close to present-day levels, Peabody can virtually eliminate fuel poverty on its estates through insulating all its homes. If fuel prices rise significantly, as is assumed in the Breaking Down scenario, then it will be difficult to prevent a fraction of Peabody residents from living in fuel poverty.

Given the lack of cost-effectiveness of the carbon reduction interventions studied, it would appear to be more cost-effective for Peabody to address fuel poverty by simply reducing rents or service charges for fuel poor households rather than refurbishing their homes. This is perhaps a surprising conclusion and contrasts sharply with the strong financial case for low-cost refurbishment measures such as cavity wall insulation or draught-proofing. A proposal like this could perhaps be practically administered on Peabody estates. If residents on estates with high fuel costs (e.g. those with electric heating, or uninsulated solid walls) were given a rent discount as compensation for their relatively expensive heating systems, this would be a cheaper way of reducing their bills than replacing heating systems. One idea discussed by Peabody staff was supplying energy on Peabody estates through a Peabody ESCo, so that fuel charges could be spread more equally across households, reducing fuel poverty in less thermally-efficient homes. The practical viability of such an approach is not clear, both in terms of its acceptability for residents and for landlords such as Peabody, and in terms of its fit with legislation on rent levels.

Although the measures considered in this research may not be worthwhile purely from a fuel poverty perspective, they may still be deemed necessary from a carbon reduction perspective. If this is the case, any fuel bill reductions that result could still greatly benefit any residents in fuel poverty, and the existence of these savings is a further argument in their favour.

9.4 Policy recommendations

This section proposes a number of key policy recommendations arising from this research. These are the need for Government to drive and enable action by social landlords (9.4.1), the need to promote demand reduction (9.4.2), and the need for grid-decarbonisation and the role of micro-generation in this process (9.4.3).

9.4.1 Driving and enabling action

The four key findings relating to Government's role in driving and enabling action was that it should:

- provide a framework on housing refurbishment for landlords and the public
- regulate to enforce action by social landlords
- create funding models and offer financial incentives to make interventions financially viable
- change existing regulations for social housing that conflict with the carbon reduction agenda

A framework should provide householders with an understanding that refurbishment is part of a nationwide effort to reduce the emissions from existing housing. The emerging concept of a "Great British Refurb" (DECC 2009d) is likely to be a useful method for positively communicating the scale of the work required. By setting out a vision for the action required to achieve deep emission cuts, the external context seen as vital by Peabody staff to make disruption to residents acceptable could be achieved.

Social landlords also need a framework to assist with their long term planning, which is likely to come through regulation on the improvements required. Many proposals exist for achieving this (Boardman 2007; EST 2008b; Housing Forum 2009). Regardless of the approach taken, the findings from this research imply that mandating action for social landlords is likely to be necessary, which conflicts with the current approach of promoting voluntary action put forward by Government (Green Futures 2008; DECC 2009a). Requiring social landlords to take a leading role in this process as recommended by Boardman (2007) appears worthwhile, given the willingness to accept this approach shown by interviewees in the scoping interview study.

A necessary complement to regulation identified in both of the qualitative studies reported in this thesis is to ensure that refurbishment is financially viable. This is a complex task, as in addition to grant funding and other financial mechanisms, it requires a number of structural barriers affecting financial viability to be addressed.

A viable funding strategy for Peabody could involve the ability to increase rents, but this is not possible in the current regulatory context. Much prior work on carbon reduction in social housing has identified this barrier, and this research supports the idea that Government should allow some flexibility for landlords to raise rents to offset refurbishment costs. Such a change in regulations would be a useful element in helping landlords to fund refurbishment, but would not provide sufficient funding on its own to make refurbishment affordable in many cases. The Government should also ensure that financial mechanisms exist that minimise the risk, upfront costs and total lifetime costs of whole-house carbon reduction interventions. A variety of mechanisms for achieving this were reviewed by the Existing Homes Alliance (2009), including the model used in Germany of providing low-cost loans to homeowners, or the method of linking repayments to a dwelling rather than a household (for example through council tax payments). A limitation of each of the funding models reviewed by the Existing Homes Alliance is that they are each designed to only incentivise interventions for which savings exceed repayment costs. The Government should therefore look to intervene through mechanisms such as grant funding to ensure that the interventions required to meet carbon reduction targets meet this criterion.

Government should enable the technical interventions identified as necessary to be taken up as rapidly as possible. For measures such as solid wall insulation which can bring immediate benefits in terms of fuel poverty reduction and job creation in the construction industry, there is little reason for delay. Proposals by the Renewable Energy Association on financial support required to incentivise micro-generation — a considerable increase on previously considered funding levels — provide a useful model to use for other measures (REA 2009). For the social housing sector, external funding covering at least 50% of costs has been recommended to stimulate the retrofitting of the social housing sector (Boardman 2007; Existing Homes Alliance 2009). Support on this scale should be pursued, as the only available alternatives are likely to be rent increases or stock sales.

Minimising the risk for social landlords was identified as an important goal. Government interventions to support this could include the development of a Guarantee Energy Trust (Hines et al. 2005), a mechanism put forward for central Government to provide capital funding and take on risk for large-scale CHP projects.

Government should look to change regulations that conflict with a social landlord's carbon reduction agenda. For example, it is currently challenging for social landlords to take advantage of the opportunity presented to carry out a comprehensive whole-house refurbishment when dwellings are vacated by tenants, because these works would mean that the dwelling would remain unlet for a longer period, and social landlords are driven by regulators to minimise the time that void dwellings are unoccupied. Proposals put forward by the Housing Forum to remove the requirement to minimise void times when such refurbishments take place (Housing Forum 2009) are a good example of regulatory changes that would benefit efforts to reduce stock emissions.

Leaseholders present a particular challenge when planning whole-estate improvements, as there is a risk that leaseholder households will not opt in for improvements such as external insulation or communal heating connections. This issue has been overcome in the past for a community heating development in Aberdeen where Energy Efficiency Commitment funding was used to cover connection charges for leaseholders, enabling all homes on the estate to be connected (King 2004). Ensuring that grant funding is standardly available for social landlords refurbishing estates with leaseholders would be of great benefit to ensure that this barrier can always be addressed.

9.4.2 Demand reduction

The need to minimise residents' demand for energy is another crucial issue. Whilst this is dependent to a large degree on broad social causes, a wide range of policies are available to Government to help reduce domestic energy demand, and these should be actively pursued. Specific policy recommendations are beyond the scope of thesis, but due to the apparent need for financial motivations for behaviour change identified in this research, policies that put a price on carbon emissions appear to be of some importance. Many approaches exist for achieving this, including Tradable Energy Quotas (Fleming 2007), carbon taxes, or the proposed Cap and Share system (Feasta 2008). Recent research by the UK Energy Research Council on the viability of meeting the Government's 80% carbon reduction target indicates that a carbon price some way beyond current levels, of £200 per tonne of CO2 (or £300-£350 if action is delayed or a more stringent target is pursued), is likely to be required to stimulate sufficient action (UKERC 2009).

9.4.3 Grid decarbonisation and micro-generation

Change external to Peabody has been shown to be vital if deep carbon emission cuts are to be achieved. Significant decarbonisation of the grid is a key issue and the targets put forward by the Committee on Climate Change (2008) for substantial grid decarbonisation offer a useful goal to work towards. To support the decarbonisation of existing housing, Government should actively pursue this goal. Government should also give an indication to social landlords on the extent of renewable electricity generation that it wishes to achieve through micro-generation on existing housing stock.

Chapter 10: Conclusions

This final chapter presents a short summary of the main findings of this research (10.1), and discussion on its original contribution to knowledge and its limitations (10.2). This is followed by a discussion on future work arising out of this thesis (10.3).

10.1 Research findings

This research has assessed the viability of achieving deep emission cuts in existing Peabody stock. The findings indicate that there is great potential to meet this goal through physical improvements to existing Peabody estates. However, if challenging carbon reduction targets are to be met, action by Government to decarbonise the grid and action by residents to constrain energy demand is also a necessity.

Substantial stock refurbishment is likely to be required for Peabody estates, with solid-walled dwellings being insulated and estates being connected to low-carbon communal heating systems where viable. To achieve deeper emission cuts, micro-generation technologies such as solar photovoltaics are likely to be required.

Even with considerable financial support from Government, these improvements will require substantial extra expenditure for Peabody of the order of tens of millions of pounds. Existing budgets are unlikely to be able to bridge this funding gap, as is likely to be the case for other social landlords. This raises an important question of where this increased funding should come from. Possible sources are the tenants themselves (through increased rents), the public (through increased Government grants or charges levied through utility companies) or through selling off social housing stock.

This study provided evidence that meeting the funding gap entirely through charges to residents is unlikely to be feasible, as due to the high costs of the measures considered, if resident charges (such as rent increases) were used to fund the considered emission reduction measures, they would outweigh fuel bill savings, leaving residents worse-off financially.

If landlords such as Peabody are to carry out the technical improvements required (alongside external changes) to achieve deep carbon emission cuts, a strong drive from Government is likely to be required. This should include mandating that action takes place, ensuring that the necessary improvements are financially viable and giving an indication to social landlords and their residents that this work is part of a UK-wide effort to retrofit existing housing. For social landlords, this could imply a widening of their key responsibilities as housing providers, with their present obligation to maintain the good condition of their stock being extended to incorporate a responsibility to actively intervene to comprehensively reduce stock emissions.

10.2 Contribution to knowledge and limitations

The primary contribution to knowledge of the present thesis comes from its analysis of the viability of achieving deep emission cuts for one social housing organisation. This fills a gap in the literature on existing research on low-carbon refurbishment of housing, which has yet to address the social housing sector in detail, or explore issues of financial viability for this sector in depth.

The majority of the findings, including the findings relating to the impacts of the considered technical interventions, represent an original contribution to knowledge with regard to the particular Peabody case study. For the social housing sector in general, the two key issues highlighted in this thesis were the need for increased funding and strong driving action from Government if deep emission cuts are to be achieved. Although these issues have been well known to many professionals working in the sector for some years (as illustrated by the scoping interview study conducted in 2006/7), this thesis has made a new contribution to this debate by providing an evidence base to support these claims. As a result, the study findings were welcomed when presented to the Social Housing group of the Energy Efficiency Partnership for Homes as important evidence to help move the debate on the low-carbon refurbishment of social housing forward.

This thesis has also provided original contributions in terms of methodology (a novel approach for modelling the impacts of displaced grid electricity, and new adaptations of the BREDEM model), in terms of a more detailed analysis of the achievement of deep cuts in emissions from housing (identifying trade-offs between technical improvements, demand reduction, decarbonisation of energy sources and changes in planning constraints) and by making a novel assessment of the viability of achieving zero net carbon emissions for existing housing estates.

The limitations of this research have been discussed throughout the thesis, and include a number of issues that were not considered in the model study (the potential role of emerging technologies, consideration of embodied energy and the impacts of climate change on energy demand) and a model approach that could only provide a broad-level analysis of interventions, costs and energy use due to the relatively simplistic model approach used and uncertainties around model assumptions and data. Many of these limitations present opportunities for further research, which are discussed in the next section.

10.3 Future work

The future work arising out of this research is discussed in terms of dissemination (10.3.1), future research focusing on Peabody (10.3.2), and future research in general (10.3.3).

10.3.1 Dissemination

As a research project that seeks to contribute to policy discussion, dissemination of results is an important issue to consider. Results of the present study have already been disseminated beyond Peabody through the publication of the report "Towards a Low Carbon Peabody" (Reeves 2009), discussion of the research findings in the social housing magazine Inside Housing in February 2009 (Inside Housing 2009), a presentation to the Social Housing group of the Energy Efficiency Partnership for Homes in April 2009, and an article in the Guardian newspaper in March 2009 (Howlett 2009). Results have been disseminated within the academic community through a poster presentation at the British Institute of Energy Economics (BIEE) conference in Oxford in September 2008, and the presentation of a peer-reviewed conference paper at the European Council for an Energy Efficient Economy (ECEEE) conference in France in June 2009 (Reeves et al. 2009).

Further dissemination will involve a presentation by the researcher at a GLA event on decentralised energy in August 2009 and academic journal articles based upon the present thesis.

10.3.2 Future research with Peabody

Future research with Peabody can be related to the recommendations arising from this research for the organisation, both in terms of practical action and organisational change. These have been communicated through discussion with Peabody staff, and the recommendations reported in Reeves (2009). The key recommendation is for Peabody to look to gain further experience of the refurbishment measures that have been identified as important for the achievement of deep emission cuts, through pilot refurbishments of existing estates.

Research on such refurbishments could be used to:

- identify technical constraints affecting the viability of carrying out the recommended measures on typical Peabody estates (high density, Victorian blocks of flats)
- reduce uncertainty around the costs of particular refurbishment measures and whole-estate refurbishments in general
- provide improved data on the actual impact of refurbishment by monitoring energy use in refurbished homes before and after work is carried out
- improve understanding of the acceptability of refurbishment to affected stakeholders, through longitudinal research exploring the organisational process of delivering the measures and the views of those involved

10.3.3 Future research

With regard to future research beyond the case study organisation studied in this thesis, a number of gaps in existing knowledge have been identified. Some implications for future research are as follows:

- As detailed in 10.3.2, research on comprehensive refurbishments of housing estates would be of great value, and could be used to improve knowledge of issues such as costs, acceptability to stakeholders, political or organisational barriers and actual impacts on energy use (through monitoring before and after the improvements).
- Studies that capture monitored data on actual energy consumption in UK social housing (and UK housing in general) would be highly beneficial to increase the knowledge of actual energy use patterns and to better inform assessments of the potential benefits of carbon reduction measures. This may require intervention from Government to make data from utility companies available to energy researchers.
- Little data is available on the embodied energy of particular carbon reduction measures (or related measures such as ventilation systems), or the wider process of carrying out whole-house refurbishments. Improved understanding of this issue will take on increasing importance as discussion on the merits of a nationwide programme of refurbishment of existing housing takes place over coming years.

- Peabody staff were concerned about the potential detrimental impacts of internal solid wall insulation in terms of the provision of adequate ventilation or a risk of over-heating. Over-heating could be a particular risk in London due to the heat island effect in the city and greater than average temperatures. Research that explores the perceptions and behaviour patterns of residents in refurbished homes after improvements, combined with quantitative analysis of internal temperatures and air quality would be beneficial to address this gap in existing knowledge, and overcome a limitation of the present thesis.
- The discussion on climate change in chapter 2 highlighted that a more ambitious carbon reduction agenda may be required than the goal of achieving 80% emission cuts by 2050 which is the focus of much present research. The discussion around emission cuts that can be achieved for distinct stock types implied that greater cuts may also be required for less-efficient existing homes. Both issues imply that further research on carbon reduction that incorporates analysis of meeting more stringent targets, as has been done in the present thesis, could be beneficial.

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Appendices

This section contains a number of pieces of background or supporting information relevant for this research. The contents of the appendices are as follows:

Appendix A: Scoping study interviews

Interview Schedule – housing association staff.

1. Introduction

- *Thank interviewee for agreeing to be interviewed.*
- *Introduce research:*
    - *Looking to identify the non-technical barriers to deep cuts in greenhouse gas emissions from housing association stock.*
    - *This could mean things like finance, government policy, regulatory drivers, organisational issues or access to support and information.*
    - *Using the Peabody Trust as a case study, and complementing this with interviews and survey research.*
- *Formalities:*
    - *Confirm permission to record interview.*
    - *Assure confidentiality, anonymisation of details in any research outputs, which means only referring to the type of organisation represented by the interviewee.*
- *Introduce structure: Around 10 fairly open-ended questions – feel free to expand as you see fit and follow your train of thought.*
- *Introduce content: Looking to find out about what is being done at your HA to improve EE and reduce emissions, and what you feel are the main drivers pushing you to act and barriers holding you back on this issue*
- *Timing:*
    - *Around an hour – 45 minutes of questions, then a short form to fill in which should take around 10 minutes.*
    - *I'll keep track of time and try to move things along if we're running behind.*
- *If a question seems unclear, ask me to clarify.*
- *Is there anything interviewee wants to ask before we go on?*

2. Discussion.

1. So first, a little about your housing association – how long has it been in existence, how many homes does it manage, and what type of homes are they?

Probe: group structure, age, building type, any stock transfers?

2. And a little about yourself – what is your role at the housing association, and how long have you been here?

Probe: responsible for refurbishment decisions?

3. First of all, could you tell me if your association has an active policy, such as an environmental, energy, or affordable warmth policy, that would impact on greenhouse gas emissions?

Probe: Active? Targets? Top-level commitment? Responsible member of staff? Success? Level of commitment?

4. Are you using or have you considered using an environmental management system such as EMAS or ISO 14001?

Probe: Why/Why not?

5. What action are you taking, at the moment or recently, that could reduce emissions from your stock?

Probe: Refurbishment – exceeding Decent Homes? Renewables? CHP? Energy Efficiency advice?

6. Do you feel that you have a good understanding of the most effective actions to take to reduce emissions from your stock?

Probe: Most effective measures? Lead on to next question

7. Do you seek out information and support to help with energy efficiency measures, and if so where from?

Probe: EST? Sustinable Homes? Websites? Colleagues? Other RSLs?

8. What impact does the Housing Corporation or government regulation have on setting the strategic priorities for your HA, and to what extent do they drive an energy saving agenda?

Probe: What are key priorities?

9. Are there any actions or policies you feel the government and the housing corporation should adopt that could lead to significant greenhouse gas emission cuts from the housing association sector?

Probe: Mandatory SAP targets? Mandatory use of XB?

10. How have you dealt with the issue of funding energy efficiency work?

Probe: Grants? ESCO approach? What is needed?

11. Have you considered using Ecohomes XB to help improve the energy efficiency of your stock?

Probe: Why? Why not? What would make you use it?

12. Do you think there are organisational issues that affect how effectively you manage energy efficiency? By this I mean things like cooperation between departments, the question of where responsibility lies or environmental values of staff?

Probe: anything above not covered

13. Obviously a big factor affecting energy usage in your stock is how tenants use energy in their homes. Is there anything you think you can do or should do to affect this?

Probe: EE advice? Educational events? Extent of obligation to interfere?

14. Aside from the issues we've discussed so far, do you feel that there are any other significant barriers to the reduction of emissions from your stock that we haven't mentioned?

15. Climate change researchers argue that we need to reduce emissions in the UK of the order of 70-90% of current levels over the next 25 years, which means cuts of that order from the HA sector. Do you think this is possible, and if so, what do you think should be done to bring this about?

Probe: possible if not compulsory?

3. Ranking of barriers.

- *I've prepared a list of potential barriers to greenhouse gas emission cuts on this sheet of paper, and I've added in some of the issues that came up in this discussion.*
- *What I'd like you to do is look through the list, and then rank how significant you think each barrier is using the scale on the right.*
- *If the meaning of any of the factors is unclear to you, please ask.*
- *If you want to add any other factors that you think are significant, please do so in the spaces at the bottom of the table.*

4. Close.

That's the end of my questions. Before I finish, I just want to check that there's nothing you want to add – anything you feel is relevant that hasn't been covered.

Finally, I just want to find out if you're willing for me to contact you again. This could be to check through any reports I produce to confirm that what I put down is what was really said, or about any potential future interviews.

Thanks very much for your time.

Appendix B: Scoping study questionnaire

Ranking of barriers to reductions of greenhouse gas emissions.

Are the following factors significant barriers to the reduction of greenhouse gas emissions from the stock of your housing association?

Rank each factor by ticking a box on the right that best matches your opinion.

FACTOR	Not at all significant	Not very significant	Quite significant	Significant	Very significant	Not applicable
Low priority in organisation						
Lack of top-level commitment						
Lack of policy commitment						
Lack of action to back up policy commitment						
Lack of cooperation between departments						
Lack of knowledge on most effective methods to reduce emissions						
Lack of support and guidance from external organisations						
Lack of knowledge of stock condition						
Difficult to get tenants to change behaviour to reduce energy use						
Work would be unpopular with tenants						
High capital costs						
Difficult to achieve payback on investment, as benefits go to tenants						

continued overleaf

FACTOR	Not at all significant	Not very significant	Quite significant	Significant	Very significant	Not applicable
Impacts on ongoing maintenance budget						
Lack of available grant funding						
Extra workload involved in applying for grant funding						
Lack of compulsory targets for emission reduction						
Management of renewables requires skills not available in-house						
Lack of a motivated individual to lead on the issue						
Lack of environmental concern from staff						
Lack of knowledge of support available						
Lack of resources for smaller housing associations						
OTHER FACTORS NOT LISTED						

Questionnaire results:

FACTOR	Number of responses						Average rating
	Not at all sig. (1)	Not very sig. (2)	Quite sig. (3)	Sig. (4)	Very sig. (5)	N/A	
High capital costs			2	4	6		4.33
Lack of compulsory targets for emission reduction		2	2	2	6		4
Lack of available grant funding		1	4	3	4		3.83
Extra workload involved in applying for grant funding		1	4	4	3		3.75
Difficult to get tenants to change behaviour to reduce energy use		1	4	6	1		3.58
Lack of resources for smaller housing associations	1		3	1	2		3.43
Difficult to achieve payback on investment, as benefits go to tenants		3	4	3	2		3.33
Impacts on ongoing maintenance budget		2	3	2	1		3.25
Lack of policy commitment	2	4	1	2	3		3
Lack of knowledge on most effective methods to reduce emissions		6	3	1	2		2.92
Lack of action to back up policy commitment		6	1	1	2	1	2.9
Lack of knowledge of support available	1	2	2	3			2.88
Lack of cooperation between departments	3	3	1	3	2		2.83
Lack of top-level commitment		7	3	1	1		2.67
Lack of support and guidance from external organisations	2	5	1	3	1		2.67
Low priority in organisation	2	4	3	3			2.58
Lack of a motivated individual to lead on the issue	2	2	1	1	1		2.57
Lack of environmental concern from staff	1	6	5				2.33
Work would be unpopular with tenants	2	5	4	1			2.33
Management of renewables requires skills not available in-house	1	7	3	1			2.33
Lack of knowledge of stock condition	6	1	2	2	1		2.25

Appendix C: Visits to Peabody

Date	Description	Comments
01/06/2006	Research meeting	On goals for research
27/06/2006	Research meeting	On BedZED and Peabody context
09/08/2006	Research meeting	On Peabody context and current actions
11/08/2006	Research meeting	On Peabody context and current actions
13/09/2006	Internal meeting	On Strawberry Vale estate
14/09/2006	Research meeting	On Rickaby Thompson's work with Peabody
14/09/2006	Research meeting	On Peabody context and current actions
14/09/2006	External meeting	With potential ESCo partner
14/09/2006	Research meeting	On Strawberry Vale estate
14/09/2006	Research meeting	On current actions
15/09/2006	Research meeting	On DECENT programme
15/09/2006	Research meeting	On utility partnerships
15/09/2006	Research meeting	On resident feedback processes
27/09/2006	Resident event	Consultation on Strawberry Vale heating
09/10/2006	Research meeting	On heating system advice
09/10/2006	Research meeting	On Coopers Road estate
09/10/2006	External meeting	Allan Jones presentation
09/10/2006	Research meeting	On Sustainability Strategy
09/10/2006	Research meeting	With property negotiators on energy efficiency advice
10/10/2006	Research meeting	On Ecohomes XB
03/11/2006	Research meeting	On Strawberry Vale
03/11/2006	Research meeting	On internal collaboration between departments
03/11/2006	Research meeting	Update on current actions
15/11/2006	Internal meeting	On Sustainability Strategy
15/11/2006	Research meeting	On DECENT
15/01/2007	Research meeting	On Green Task Force
16/01/2007	Internal meeting	Launch of green task force
12/02/2007	Research meeting	Update on current actions
12/02/2007	Research meeting	On monitoring actual energy use
26/02/2007	Research meeting	On monitoring actual energy use
26/02/2007	Research meeting	On Peabody's context and goals
26/02/2007	Research meeting	As above, and update on current actions
16/03/2007	Research meeting	Update on current actions
11/04/2007	External meeting	On potential district heating connection
11/04/2007	Research meeting	Update on current actions
03/05/2007	Internal meeting	Green Task Force meeting
21/05/2007	Research meeting	Update on current actions
21/05/2007	Research meeting	Green Task Force meeting
22/05/2007	Research meeting	Update on current actions
22/05/2007	Research meeting	Update on current actions
01/06/2007	External meeting	Meeting with potential utility partner
01/06/2007	Research meeting	On Peabody's broad context
20/06/2007	Internal meeting	Green Task Force meeting
05/07/2007	Internal meeting	Green Task Force property subgroup meeting
06/07/2007	Internal meeting	Presentation by Dwyer of research findings
06/07/2007	Research meeting	Discussion on goals for my research
26/07/2007	Internal meeting	Green Task Force property subgroup meeting
26/07/2007	Internal meeting	Green Task Force meeting
16/08/2007	Research meeting	On data for PEM
06/09/2007	Research meeting	On data for PEM
06/09/2007	Research meeting	Planning workshop for residents' conference
07/09/2007	Research meeting	On 21st Century Peabody project
07/09/2007	Research meeting	On 21st Century Peabody project
15/09/2007	Presentation and resident event	Peabody residents' conference
20/09/2007	Research meeting	Feedback on conference
18/10/2007	Research meeting	On decent homes actions
18/10/2007	Research meeting	On 21st Century Peabody project
18/10/2007	Research meeting	On BedZED

18/10/2007	Research meeting	On potential district heating connection
18/10/2007	Internal meeting	Green Task Force meeting
01/11/2007	Research meeting	On decent homes actions
01/11/2007	Research meeting	On data for PEM
15/01/2008	External meeting	Meeting with GLA's Decentralised Energy Group
15/01/2008	Research meeting	On approach to economic appraisal for PEM
01/05/2008	Research meeting	Update on current actions
01/05/2008	Presentation	For 21st Century Peabody Project Sounding Board
08/05/2008	Research meeting	Update on current actions
14/05/2008	Presentation	For Peabody's Resident Community Committee
22/05/2008	Internal meeting	1st meeting for Physical subgroup for 21st Century Project
06/06/2008	Internal meeting	2nd meeting for Physical subgroup for 21st Century Project
16/06/2008	Internal meeting	3rd meeting for Physical subgroup for 21st Century Project
24/06/2008	Internal meeting	4th meeting for Physical subgroup for 21st Century Project
17/07/2008	Presentation	For 21st Century Peabody Project Sounding Board
05/11/2008	Research meeting	Update on current actions
23/12/2008	Research meeting	Review of methodology for “Towards a Low Carbon Peabody” report
12/02/2009	Presentation and Internal meeting	On media strategy for disseminating research findings
12/02/2009	Research meeting	Update on current actions
20/02/2009	Research meeting	Final interview on research findings

Appendix D: Final interview schedule

Interview schedule: final interview with Peabody staff on 20/2/09

Introduction:

- Interview aims: identifying factors – which could be internal or external to Peabody – that are either holding back progress on achieving emission cuts, or that you think are necessary to move this work forwards. I'm also looking for a sense of Peabody's thinking about this issue.
- Keep in mind that I'm considering the period up to 2030, not just the present day.
- It would be great to hear something from each of you for each question (if you feel there is something to add).
- I want it to be an open discussion, so we can follow the conversation where it takes us.
- Check that it is OK for discussion to be recorded
- Confirm that outputs will be checked with Peabody prior to publication.

Questions:

1. How would you describe Peabody's current broad agenda with regards to carbon emission reduction (over the short term and the long term)?
Probe: How is it framed? (Doing what it can? Keeping up with regulations? Pursuing deep cuts?)

2. If an agenda of pursuing deep emission cuts was pursued – 60% and beyond - what would the motivation be for this?
Probe: Possible without compulsion? Could any other drivers such as fuel poverty or an internal commitment bring this about?

3. I've suggested that the most effective intervention for Peabody to carry out is applying solid wall insulation where it's needed. This would involve using internal wall insulation on conservation area estates, and could even involve decanting residents on these estates if a more rapid roll-out was pursued.
What are your thoughts on the viability of solid-wall insulation as a measure?
Probe: Drivers? Barriers? Acceptability to residents? Issues around decanting? Under what circumstances could this be done?

4. I've also suggested that on suitable estates Peabody carries out communal heating connections to replace individual gas boilers – either by connecting to district heating networks or by installing communal biomass boilers on its estates - and that gas-fired CHP seems to be less effective than these two approaches.
What are your thoughts on the viability of these technologies?
Probe: Drivers? Barriers? Acceptability to residents? Management for Peabody (ESCo)? Under what circumstances could this be done?

5. Micro-generation technologies such as solar photovoltaics or solar thermal could be necessary to achieve deeper cuts, or if external change is slow. Also ground or air source heat pumps could be useful if the grid is substantially decarbonised.
What are your thoughts on the viability of these technologies?
Probe: Drivers? Barriers? Acceptability to residents? Management for Peabody (ESCo)? Under what circumstances could this be done?

6. Each approach I consider for meeting the 2025 target has a funding gap associated with it. A total decrease in NPV of between -£30m and -£110m, or extra net expenditure to 2030 of £70m to £160m. What are your thoughts on the financial viability of meeting the GLA target for Peabody stock?
Probe: Drivers? Barriers? Acceptability to residents? Fuel poverty? Under what circumstances could it be done? Possible approaches for bridging gap?

7. It is important that my research findings are as valid as possible, and it would be useful to get your views on this. So, in what ways do they either backup or go against your understanding of Peabody's situation?
Prove: Anything that seems doubtful? Trust in cost estimates?

9. To summarise, could you briefly let me know the main barriers to achieving deep emission cuts in Peabody stock up to 2030 as you see them, and what main changes you think need to happen (if any) to make meeting the GLA target viable?

10. Is there anything else you'd like to add – things you consider to be important that we have not discussed?

Close:

- Thank interviewees for their time.

Appendix E: Peabody conference survey

Energy use in your home

This survey is being conducted by De Montfort University, as part of a project that looks to reduce greenhouse gas emissions from Peabody Trust homes. Your views are very valuable to us, and will help us with this work.

Please answer all the questions as accurately as you can. There are no wrong or right answers. Your responses are anonymous and confidential, with all information collected stored in a secure location. The survey should take less than 5 minutes to complete.

If you would like to find out more about the results of the questionnaire, please contact Andrew Reeves at De Montfort University at areeves@dmu.ac.uk. Thank you very much for your help.

1. How many of the lights in your home are fitted with energy saving light bulbs?

None	☐	*Most (around ¾)*	☐
Some (around ¼)	☐	*All*	☐
Half	☐	*Don't know*	☐

2. If you have a thermostat in your home, what temperature do you set it to in winter?

Don't have a thermostat	☐	*21°*	☐
17° or lower	☐	*22°*	☐
18°	☐	*23° or higher*	☐
19°	☐	*Don't know*	☐
20°	☐		

3. How do you heat your home during the winter? Tick all that apply.

Radiators (heated by gas central heating)	☐
Gas fire(s)	☐
Electric storage heaters	☐
Portable electric heater(s)	☐
Portable gas heater(s)	☐
Radiators (heated by communal heating system)	☐

4. What parts of your home do you normally heat during winter?

Whole home	☐
Only occupied rooms	☐
Only living room	☐

5. When do you heat your home during a normal winter weekday?

All day and overnight (24 hours)	☐
All day (from morning until end of evening)	☐
Morning and evening (turned off in afternoon)	☐
Evenings only	☐

Other (please specify): ____

please turn over

6. Is your home as warm as you would like it to be during winter?

Yes, it's comfortable ☐
No, it's colder than I would like ☐

7. If you answered "No" to question 6, why do you think your home is colder than you would like? (tick all that apply)

Home doesn't stay warm ☐
Heating is difficult to control ☐
Saving money by using heating less ☐
Saving energy to be environmentally friendly ☐
Other (please specify): ____

8. An energy saving appliance is a machine (like a fridge or a washer-dryer) that uses less energy and costs less money to run. The Peabody Trust are considering setting up a scheme to enable their residents to buy energy saving appliances for a discount price. If this happened, would you consider buying an energy saving appliance through Peabody in the future?

Yes	☐	*Maybe*	☐
No	☐	*Don't know*	☐

9. Information about you and your household.

9a. Your gender: Male ☐ Female ☐

9b: Your age:

16-24	☐	40-64	☐	80+	☐
25-39	☐	65-79	☐		

9c. How many people live in your home?

_______ Adults _______ Children (16 or under)

9d. What is the address of your home?

Flat/House Number: _______________
Address: ____
____
Postcode: ________________________

Thank you for taking time to complete the survey. Please return it to a Peabody Trust staff member (along with your conference feedback form) at the end of the day.

Data protection statement
Any personal information will be handled under the terms of the Data Protection Act. Any information that you supply will be used by De Montfort University for research purposes only. The information you supply will not be passed to any other organisation and will not be used for any other purpose. Information, if published, will be in aggregated form so that individual household's data can not be identified. Individual household data will be held securely and disposed of when its purpose for collection is over.

Conference survey results:

1. How many of the lights in your home are fitted with energy saving light bulbs?

Response	Frequency	Percentage
None	11	15%
Some (around ¼)	13	18%
Half	13	18%
Most (around ¾)	17	24%
All	16	22%
Don't know	1	1%
No response	1	1%

2. If you have a thermostat in your home, what temperature do you set it to in winter?

Response	Frequency	Percentage
17° or lower	4	6%
18°	4	6%
19°	1	1%
20°	18	25%
21°	5	7%
22°	4	6%
23° or higher	2	3%
Don't have a thermostat	20	28%
Don't know	11	15%
No response	3	4%

3. How do you heat your home during the winter? Tick all that apply.

Response	Frequency	Percentage
Gas central heating	46	64%
Communal heating	4	6%
Electric storage heaters	3	4%
Gas central heating and gas fire	4	6%
Gas central heating and portable electric heaters	2	3%
Gas fire	4	6%
Gas fire and electric storage heaters	1	1%
Gas fire and portable electric heaters	4	6%
Portable electric heaters	2	3%
Portable electric heaters and underfloor heating	1	1%
No response	1	1%

4. What parts of your home do you normally heat during winter?

Response	Frequency	Percentage
Whole home	27	38%
Only occupied rooms	33	46%
Only living room	12	17%

5. When do you heat your home during a normal winter weekday?

Response	Frequency	Percentage
All day and overnight (24 hours)	5	7%
All day (from morning until end of evening)	13	18%
Morning and evening (turned off in afternoon)	29	40%
Evenings only	16	22%
Other	9	13%

6. Is your home as warm as you would like it to be during winter?

Response	Frequency	Percentage
Yes	55	76%
No	16	22%
No response	1	1%

7. If you answered "No" to question 6, why do you think your home is colder than you would like? (tick all that apply)

Response	Frequency	Percentage
Home doesn't stay warm	8	44%
Heating is difficult to control	0	0%
Saving money by using heating less	3	17%
Saving energy to be environmentally friendly	1	6%
Saving energy and saving money	2	11%
Home doesn't stay warm, saving money and saving energy	1	6%
Home doesn't stay warm, saving money and other	1	6%
Other	2	11%

8. An energy saving appliance is a machine (like a fridge or a washer-dryer) that uses less energy and costs less money to run. The Peabody Trust are considering setting up a scheme to enable their residents to buy energy saving appliances for a discount price. If this happened, would you consider buying an energy saving appliance through Peabody in the future?

Response	Frequency	Percentage
Yes	34	47%
Maybe	22	31%
No	5	7%
Don't know	6	8%
No response	5	7%

9. Information about you and your household.

9a. Your gender:

Response	Frequency	Percentage
Male	19	26%
Female	50	70%
No response	3	4%

9b: Your age:

Response	Frequency	Percentage
16-24	1	1%
25-39	4	6%
40-64	32	44%
65-79	26	36%
80+	6	8%
No response	3	4%

9c. How many people live in your home?

Response	Frequency	Percentage
1 adult	39	54%
1 adult, 1 child	2	3%
1 adult, 2 children	2	3%
2 adults	12	17%
2 adults, 1 child	1	1%
2 adults, 2 children	1	1%
2 adults, 5 children	1	1%
3 adults	4	6%
3 adults, 1 child	1	1%
3 adults, 2 children	1	1%
4 adults	2	3%
4 adults, 1 child	1	1%
No response	5	7%

Appendix F: Initial template

A priori codes are shown in bold.

1st level	2nd level	3rd level
Behavioural interventions		
	Billing	
	Controls	
	Feedback monitors	
	Guidance and advice	
External context		
	Broad context	
	Government and regulators	
	Industry	
	Local authorities	
	Social landlords	
	Support	
	Utilities	
Facilitating actions		
	Externally oriented	
		21st Century Peabody
		Conference
		ESCO
		Influencing
		Partnerships
	Internal processes	
		Budget
		Dedicated staff
		Grant funding
		Green Task Force
		Personal performance targets
		Sustainability Strategy
	Monitoring progress	
		Ecohomes XB
		EPCs
		SAP
		SHIFT
	Research	
		Dwyer
		Reeves
		Rickaby Thomson
Internal capacity		
	Information	
		Information searching
		Interventions
		Staff knowledge
		Stock and residents
		Trust
		Uncertainty
	Skills and capabilities	
Internal factors		
	Organisational behaviour	
		Carbon reduction agenda
		Decision making processes
		Direction of organisation
		Higher management
		Prioritisation
		Responsibility
		Silos
		Strategic approach
	Other goals	

		Audit performance
		Efficiency
		Gas safety checks
		Maintenance burden
		New development
		Tenant satisfaction
		Void times
	Staff attitudes, views and framing	
		Attitudes towards interventions
		Hassle and complexity
		Low-carbon retrofitting
		Main barriers
		Peabody stock
		Peabody's role
		Values
Financial issues		
	Accounts	
	Approach to financial decisions	
	Capital and loans	
	Financial burden of Peabody stock	
	Financial viability	
	Funding approaches	
	High costs	
	Risk	
	Sharing benefits	
Motivation		
	Competitiveness	
		Economic
		Reputation
	Ecological and social responsibility	
		Climate change
		Committed staff
		Fuel Poverty
	Legitimation	
		Compliance culture
		Existing regulation
		Future regulation
		Sector norms
Residents		
	Acceptability of interventions	
	Energy use behaviour	
	Leaseholders	
	Priorities	
Technical interventions		
	Appliances and lighting	
	Communal heating	
		Biomass
		CHP
		District Heating
	DECENT and SOUND	
	Estates	
		Abbey Orchard
		BedZED
		Coopers Road
		Nags Head
		Strawberry Vale
	Fabric	
		Demolition and rebuild

		Materials
		Passivhaus Refurbishment
	Future technologies	
	Futureproofing	
	Individual heating	
		Electric heating
		Gas central heating
		Heat pumps
		MicroCHP
	Pilot Refurbishment	
	Solar Panels	
		Solar PV
		Solar Thermal

Appendix G: Final template

A priori codes are shown in bold.

Level 1	Level 2	Level3
Behavioural interventions		
	Feedback monitors	
	Guidance and advice	
External context		
	Broad context	
	Government and regulators	
	Industry	
	Local authorities	
	Social landlords	
	Support	
	Utilities	
Facilitating actions		
	Externally oriented	
		21st Century Peabody
		ESCO
		Influencing
		Partnerships
	Internal processes	
		Dedicated staff and budget
		Green Task Force
		Sustainability Strategy
	Monitoring progress	
		Ecohomes XB
		EPCs
		SAP
		SHIFT
	Research	
		Dwyer
		Reeves
		Rickaby Thomson
Financial issues		
	Capital and loans	
	Financial burden of Peabody stock	
	Financial viability	
	Funding approaches	
		Grant funding
		Sharing benefits
	Risk	
Internal resources		
	Information	
		Information searching
		Interventions
		Staff knowledge
		Stock and residents
	Skills and capacity	
		Existing problems
		Time
Motivation		
	Competitiveness	
		Economic
		Reputation
	Ecological and social responsibility	
		Climate change

		Fuel Poverty
		Values and staff commitment
	Legitimation	
		Compliance culture
		Existing regulation
		Future regulation
Residents		
	Acceptability of interventions	
	Energy use behaviour	
	Leaseholders	
	Priorities	
Staff attitudes, views and framing		
	Attitudes towards interventions	
	Main barriers	
	Peabody stock	
	Peabody's role	
Strategy and management		
	Carbon reduction agenda	
	Decision making processes	
	Direction of organisation	
	Other goals	
		Audit performance
		New development
		Tenant satisfaction
		Void times
	Prioritisation	
	Responsibility	
	Senior management	
	Strategic approach	
Technical interventions		
	Appliances and lighting	
	BedZED	
	Communal heating	
		Biomass
		CHP
		District Heating
		Strawberry Vale
	DECENT and SOUND	
	Demolition and rebuild	
	Fabric	
	Future technologies	
	Futureproofing	
	Individual heating	
		Electric heating
		Gas central heating
		Heat pumps
		MicroCHP
	Pilot Refurbishment	
	Solar Panels	
	Wind turbines	

Appendix H: Assumptions by scenario

Assumption	Keeping the Lights On	Sustainable Development	Power Down	Breakdown
Annual change in electricity Carbon Intensity (2011 to 2030)	-0.0099 $kgCO_2/kWh$	-0.0174 $kgCO_2/kWh$	As for SD	As for KLO
Annual change in percentage of energy used by energy efficient lighting relative to incandescent lighting (2015 to 2030)	-0.266%	-1.3%	As for SD	As for KLO
Annual percentage changes in energy demand (lighting; electricity; heat; hot water; cooking), 2011 to 2016; 2017 to 2030	Lighting: no change Electricity: increases annually by 1.65% to 2030 Heat: no change Hot water: no change Cooking: no change	Lighting: -2% per annum to 2016 then no change Electricity: no change to 2016 then -1% Heat: -2% to 2016, then no change to 2030 Hot water: -2% to 2016, then no change Cooking: -2% to 2016, then no change	Lighting: -2% to 2016 then -1% Electricity: no change to 2016 then -2% to 2030 Heat: -2% to 2016, then -1% to 2030 Hot water: -2% to 2016, then -1% to 2030 Cooking: -2% to 2016, then -1% to 2030	Lighting: No change to 2016 then -1% to 2030 Electricity: 1.65% to 2016 then -1% to 2030 Heat: no change to 2016, then -1% to 2030 Hot Water: no change to 2016, then -1% to 2030 Cooking: No change, then -1% to 2030
Gas prices (2009 to 2030)	1%	1.5%	2.5%	3.5%
Electricity prices (2009 to 2030)	1%	2.5%	3.5%	3%
District Heating change in carbon intensity of input fuel (2006 to 2030)	0	-0.0046 $kgCO_2/kWh$	As for SD	As for KLO
Fraction of homes in Low Carbon Zone	0	21%	30%	0
Fraction of renewables costs covered by grants	5%	30%	20%	5%
Fraction of insulation costs covered by grants	5%	20%	30%	10%
Percentage of estates with possible district heating connection	10%	25%	25%	10%
Discount rate	3.5%	3.5%	2% (0.5% net growth	1.5% (zero net growth)
Feed in tariffs?	No	Yes	No	No
Renewable Heat Obligation?	No	Yes	Yes	No
Annual reduction in costs for PV	2.5%	5.5%	5.5%	2.5%
Annual reduction in costs for other micro-generation (ASHPs, GSHPs & Biomass CHP)	1%	4%	4%	1%

Appendix I: Sensitivity analysis variables

Factor	Variable(s)	Original Value	Low Value	High Value
Average floor areas	Correction factor used to calculate average floor areas	K = 0.92	K = 0.84	K = 1
Base energy demand	Base demand for electricity, lighting, heating, hot water and energy for cooking, relative to modelled estimates	Electricity 10% less than modelled estimate, all other uses as for equations described above	Electricity 28% less than modelled estimate, all other uses 20% less than modelled estimate	Electricity 8% above modelled estimate, all other uses 20% above modelled estimate
Base fuel costs	Base standing charges and unit costs for gas and electricity for residents and Peabody	Various values, as given in chapter 5.	All costs reduced by 20%	All costs increased by 20%
Base Peabody fuel costs	2006 costs of gas and electricity for Peabody	Gas 2.3p per unit; electricity 8.6p per unit	Gas 1.9p per unit; electricity 6.9p per unit	Gas 2.8p per unit; electricity 10.4p per unit
Change in ROC price	Change in income received through ROCs for renewable electricity	No change from 2011	Annual 1% decrease from 2011	Annual 1% increase from 2011
CHP elec. efficiency	CHP electrical efficiency	28%	21%	35%
CHP heat efficiency	CHP heat efficiency	50%	43%	57%
CHP running hours	Running hours for CHP systems providing base hot water load	6200 hours per year	5000 hours per year	6800 hours per year
Communal boiler efficiency	Communal boiler efficiency	85%	80%	90%
Cost of administering CHP/communal heating	Annual cost of billing residents; costs per dwelling of buying electricity meters and internal wiring	£52 billing cost per dwelling; £277 per dwelling to buy internal wiring; £26 per dwelling to buy electricity meters	£41 billing cost per dwelling; £138 per dwelling to buy internal wiring; £13 per dwelling to buy electricity meters	£62 billing cost per dwelling; £415 per dwelling to buy internal wiring; £39 per dwelling to buy electricity meters
Cost of CHP	Installation and annual maintenance costs for CHP	£4459 fixed cost per dwelling; £2229 variable cost per kWe installed; £114 per dwelling annual maintenance costs	£2229 fixed cost per dwelling; £1115 variable cost per kWe installed; £57 per dwelling annual maintenance costs	£6689 fixed cost per dwelling; £3345 variable cost per kWe installed; £171 per dwelling annual maintenance costs
Cost of district heating	Cost of district heating	£7690 per dwelling	£5183 per dwelling	£10198 per dwelling
Cost of double glazing	Cost of double glazing	£1017 per m^2 installed	£814 per m^2 installed	£1220 per m^2 installed

Cost of fabric measures	Costs of gas boiler installation, gas connection, TRVs, heat meters and extractor fans	Boiler installation: £5529; Gas connection: £1516; TRVs: £239; Heat meters: £2391; Extractor fans: £892	Boiler installation: £4423; Gas connection: £758; TRVs: £120; Heat meters: £1674; Extractor fans: £713	Boiler installation: £6635; Gas connection: £2274; TRVs: £359; Heat meters: £3108; Extractor fans: £1070
Cost of gas boilers	Annual maintenance and replacement costs for individual gas boilers	£142 per dwelling annual maintenance, £2844 for replacement	£114 per dwelling annual maintenance, £2275 for replacement	£170 per dwelling annual maintenance, £3412 for replacement
Cost of insulation	Cost of external, internal and floor insulation	£188 per m^2 external; £112 per m^2 internal; £88 per m^2 floor	£94 per m^2 external; £56 per m^2 internal; £44 per m^2 floor	£282 per m^2 external; £167 per m^2 internal; £131 per m^2 floor
Cost of maintaining non-gas CH services	Cost of maintenance & replacement for gas cookers, electric heating and existing communal heating	Electric heating: £2844 replacement cost, £15 per annum maintenance; Existing communal heating: £1580 per unit replacement cost, £37 per unit annual maintenance; Gas cookers: £52 per dwelling annual maintenance costs	Electric heating: £1991 replacement cost, £8 per annum maintenance; Existing communal heating: £1264 per unit replacement cost, £30 per unit annual maintenance; Gas cookers: £26 per dwelling annual maintenance costs	Electric heating: £3697 replacement cost, £22 per annum maintenance; Existing communal heating: £1896 per unit replacement cost, £44 per unit annual maintenance; Gas cookers: £78 per dwelling annual maintenance costs
Displaced grid carbon intensity	Carbon emission savings by CHP/PV electricity generation (that displace grid electricity)	As defined in chapter 5	From 2006, declines linearly from 0.568 $kgCO_2/kWh$, to reach 0 as grid carbon intensity reaches 0.	Remains at 0.568 $kgCO_2/kWh$ from 2006 to 2030
District heating emissions	District Heating emissions from gas use per kWh heat generated ($kgCO_2/kWh$)	0.33	0.297	0.363
Effectiveness of insulation	Effectiveness of insulation measures in achieving expected heat demand reduction	Achieves 85% of modelled demand reduction	Achieves 50% of modelled demand reduction	Achieves 100% of modelled demand reduction
Estates suitable for communal heating	Percentage of estates suitable for communal heating	80%	60%	100%
Estimated heat demand	Figures for annual heat demand per square metre for each dwelling type	Various values from Firth (2008)	All values reduced by 20%	All values increased by 20%
Exports of generated electricity	Percentage of electricity exported where electricity generated onsite is sold to residents	50%	30%	70%

External wall area	Assumed average external wall areas	As per equations described above	20% less than original assumption	20% more than original assumption
FIT rate	Feed-in tariff level for PV, and PV lifespan used for FIT calculation	34.5p per unit generated in 2011, assumed lifespan of 10 years	25p per unit generated in 2011, assumed lifespan of 10 years	45p per unit generated in 2011, assumed lifespan of 25 years
Gas boiler efficiency	Efficiency of new individual gas boilers	90%	86%	94%
Home needing TRVs/Fans	Fraction of homes needing TRVs and extractor fans after Decent Homes	80% needing fans; 75% needing TRVs	65% needing fans; 60% needing TRVs	95% needing fans; 90% needing TRVs
Lifespan of communal systems	Lifespans of non-gas boiler heating systems	15 years	12 years	18 years
Lifespan of fabric measures	Lifespans of insulation, glazing, heat meters and communal infrastructure	30 years for solid wall insulation, floor insulation, communal infrastructure and heat meters; 20 years for glazing	20 years for solid wall insulation, floor insulation, communal infrastructure and heat meters;; 20 years for glazing	40 years for solid wall insulation, floor insulation, heat meters and communal infrastructure; 24 years for glazing
Lifespan of gas boilers	Lifespan of gas boilers	12 years	9 years	15 years
Lifespan of solar systems	Lifespans of solar systems	25 years	20 years	30 years
Lifespan of storage heaters	Lifespan of storage heaters	20 years	16 years	24 years
Max. use of onsite-generated electricity	Maximum proportion of onsite generated electricity that can be used onsite	80% of electricity generated	60% of electricity generated	90% of electricity generated
Number of disposals	Number of units sold from 2006 to 2011	599	400	800
Original boiler efficiencies	Efficiency of original boilers for heat and hot water	Various values from SAP 2005	All values reduced by 10%	All values increased by 5%
Price for elec. exports	Price received in 2006 for electricity exports to the grid	1.7p per unit exported	1p per unit exported	6p per unit exported
Pumps, fans and HW losses	Energy used by pumps and fans, and scale of losses from hot water systems	As assumed based upon BREDEM equations.	30% less energy used/lost than assumed orginally	30% more energy used/lost than assumed orginally
PV costs	PV Costs for installation and maintenance	£986 per kWe installation costs; £7.1 per m^2 annual maintenance costs	£690 per kWe installation costs; £5 per m^2 annual maintenance costs	£1282 per kWe installation costs; £9.2 per m^2 annual maintenance costs
PV output	PV annual output per m^2 (kWh)	90 (flat roof); 88 (south-facing); 75 (east/west-facing)	81 (flat roof); 79.2 (south-facing); 67.5 (east/west-facing)	99 (flat roof); 96.88 (south-facing); 82.5 (east/west-facing)
RHO rate	Renewable heat obligation rate	2p per unit of renewable heat generated	1p per unit of renewable heat generated	3p per unit of renewable heat generated

Roof space for solar panels	Fraction of roof space suitable for solar panels	50% for flat roofs, 75% for pitched	25% for flat roofs, 40% for pitched	65% for flat roofs, 80% for pitched
Size of terminal values	Size of terminal values assumed for NPV calculations	As defined in chapter 5	20% less than original assumption	20% more than original assumption
Solar thermal costs	Solar thermal installation and maintenance costs	£2690 per dwelling fixed costs; £1284 per kWth variable costs; £57 annual maintenance costs	£1883 per dwelling fixed costs; £899 per kWth variable costs; £40 annual maintenance costs	£3497 per dwelling fixed costs; £1669 per kWth variable costs; £74 annual maintenance costs
Solar Thermal Output	Solar Thermal annual output per m^2 (kWh)	400	340	460
Turnover of residents	Annual Turnover of Residents	4%	2%	6%
Use of energy saving lighting	Use of energy saving lighting (fixed)	55% originally, 5% annual increase to 2015	37% originally, 7% annual increase to 2015	73% originally, 3% annual increase to 2015
	Use of energy saving lighting (non-fixed)	0% originally, 11% annual increase to 2015	0% originally, 4.2% annual increase to 2030	As for original value
Use of pumps for communal heating	Energy used for pumping hot water	4% of communal heat output	2% of communal heat output	6% of communal heat output
Window area on external walls	Assumed average window areas	As per equations described above	20% less than original assumption	20% more than original assumption

All scenarios: sensitivity analysis assumptions

Factor	Variable	Original Value	Low Value	High Value
Discount rate	Discount rate	3.5%	1.5%	5.5%
District heating availability	Fraction of estates with possible district heating connections	10%	5%	15%
Elec. carbon intensity	Carbon Intensity of electricity ($kgCO_2$/kWh)	Annual reduction of 0.0099 from 2011 to 2030	Annual reduction of 0.00175 from 2011 to 2030	No change from 2011
Energy demand change	Resident demand for heat, hot water, lighting and energy for cooking	No change	Annual reduction of 1% from 2011 to 2030	Annual increase of 1% from 2011 to 2030
	Resident electricity demand	1.65% annual increase to 2030	0.65% annual increase to 2030	2.65% annual increase to 2030
Energy saved by EE lighting	Change in fraction of lighting energy use saved by energy-efficient lighting	0.27% annual increase in energy saving from 2015	No change from 2015	1.3% annual increase in energy saving from 2015
Grant funding for insulation	Fraction of insulation cost covered by grants	5%	0%	20%
Grant funding for renewables	Fraction of renewables cost covered by grants	5%	0%	20%
Grid elec. price change	Annual change in electricity prices from 2009	Annual increase of 1%	Annual decrease of 1%	Annual increase of 3%

Grid gas price change	Annual change in gas prices from 2009	Annual increase of 1%	Annual decrease of 1%	Annual increase of 3%
Learning rate for renewables	Change in costs for PV	Annual decrease of 2.5% from 2011	Annual decrease of 5% from 2011	No change
	Change in costs for solar thermal and heat pumps	Annual decrease of 1% from 2011	Annual decrease of 2% from 2011	No change
No. estates in low carbon zones	Percentage of estates in low carbon zones	0%	0%	10%

KLO scenario: sensitivity analysis

Factor	Variable	Original Value	Low Value	High Value
Discount rate	Discount rate	3.5%	1.5%	5.5%
District heating availability	Fraction of estates with possible district heating connections	25%	10%	40%
Elec. carbon intensity	Carbon Intensity of electricity / $kgCO_2$/ kWh	Annual reduction of 0.00175 from 2011 to 2030	Annual reduction of 0.0269 from 2011 to 2030	Annual reduction of 0.0099 from 2011 to 2030
Energy demand change	Resident demand for heat, hot water, lighting and energy for cooking	Annual reduction of 2% from 2011 to 2016, then no change	Annual reduction of 3% from 2011 to 2016, then of 1% until 2030	Annual reduction of 1% from 2011 to 2016, then annual 1% increase until 2030
	Resident electricity demand	No change to 2016, then annual 1% reduction to 2030	Annual 1% reduction to 2016, then annual 2% reduction to 2030	Annual 1% increase to 2016, then no change to 2030
Energy saved by EE lighting	Change in fraction of lighting energy use saved by energy-efficient lighting	1.3% annual increase in energy saving from 2015	0.27% annual increase in energy saving from 2015	As for original
Grant funding for insulation	Fraction of insulation cost covered by grants	20%	5%	35%
Grant funding for renewables	Fraction of renewables cost covered by grants	30%	10%	50%
Grid elec. price change	Annual change in electricity prices from 2009	Annual increase of 2.5%	Annual increase of 0.5%	Annual increase of 4.5%
Grid gas price change	Annual change in gas prices from 2009	Annual increase of 1.5%	Annual decrease of 0.5%	Annual increase of 3.5%
Learning rate for renewables	Change in costs for PV	Annual decrease of 5.5% from 2011	Annual decrease of 8% from 2011	Annual decrease of 3% from 2011
	Change in costs for solar thermal and heat pumps	Annual decrease of 4% from 2011	Annual decrease of 6% from 2011	Annual decrease of 2% from 2011
No. estates in low carbon zones	Percentage of estates in low carbon zones	21%	10%	30%

SD scenario: sensitivity analysis assumptions

Factor	Variable	Original Value	Low Value	High Value
Discount rate	Discount rate	2%	0%	4%

District heating availability	Fraction of estates with possible district heating connections	25%	10%	40%
Elec. carbon intensity	Carbon Intensity of electricity / $kgCO_2$/ kWh	Annual reduction of 0.00175 from 2011 to 2030	Annual reduction of 0.0269 from 2011 to 2030	Annual reduction of 0.0099 from 2011 to 2030
Energy demand change	Resident demand for heat, hot water, lighting and energy for cooking	Annual reduction of 2% from 2011 to 2016, then annual 1% reduction to 2030	Annual reduction of 3% from 2011 to 2016, then of 2% until 2030	Annual reduction of 1% from 2011 to 2016, then no change until 2030
	Resident electricity demand	No change to 2016, then annual 2% reduction to 2030	Annual 1% reduction to 2016, then annual 3% reduction to 2030	Annual 1% increase to 2016, then annual 1% reduction to 2030
Energy saved by EE lighting	Change in fraction of lighting energy use saved by energy-efficient lighting	1.3% annual increase in energy saving from 2015	0.27% annual increase in energy saving from 2015	As for original
Grant funding for insulation	Fraction of insulation cost covered by grants	30%	10%	50%
Grant funding for renewables	Fraction of renewables cost covered by grants	20%	5%	35%
Grid elec. price change	Annual change in electricity prices from 2009	Annual increase of 3.5%	Annual increase of 1.5%	Annual increase of 5.5%
Grid gas price change	Annual change in gas prices from 2009	Annual increase of 2.5%	Annual increase of 0.5%	Annual increase of 4.5%
Learning rate for renewables	Change in costs for PV	Annual decrease of 5.5% from 2011	Annual decrease of 8% from 2011	Annual decrease of 3% from 2011
	Change in costs for solar thermal and heat pumps	Annual decrease of 4% from 2011	Annual decrease of 6% from 2011	Annual decrease of 2% from 2011
No. estates in low carbon zones	Percentage of estates in low carbon zones	30%	21%	40%

PD scenario: sensitivity analysis assumptions

Factor	Variable	Original Value	Low Value	High Value
Discount rate	Discount rate	1.5%	-0.5%	3.5%
District heating availability	Fraction of estates with possible district heating connections	10%	5%	15%
Elec. carbon intensity	Carbon Intensity of electricity / $kgCO_2$/ kWh	Annual reduction of 0.0099 from 2011 to 2030	Annual reduction of 0.00175 from 2011 to 2030	No change from 2011
Energy demand change	Resident demand for heat, hot water, lighting and energy for cooking	No change from 2011 to 2016, then annual 1% reduction to 2030	Annual 2% reduction from 2011 to 2016, then annual 1% reduction to 2030	Annual 1% increase from 2011 to 2016, no change to 2030
	Resident electricity demand	1.65% annual increase from 2011 to 2016, then annual 1% reduction to 2030	0.65% annual increase from 2011 to 2016, then annual 2% reduction to 2030	2.65% annual increase from 2011 to 2016, then no change to 2030

Energy saved by EE lighting	Change in fraction of lighting energy use saved by energy-efficient lighting	0.27% annual increase in energy saving from 2015	No change from 2015	1.3% annual increase in energy saving from 2015
Grant funding for insulation	Fraction of insulation cost covered by grants	10%	0%	20%
Grant funding for renewables	Fraction of renewables cost covered by grants	5%	0%	10%
Grid elec. price change	Change in electricity prices from 2009	Annual increase of 3%	Annual increase of 1%	Annual increase of 5%
Grid gas price change	Change in gas prices from 2009	Annual increase of 3.5%	Annual increase of 1.5%	Annual increase of 5.5%
Learning rate for renewables	Change in costs for PV	Annual decrease of 2.5%	Annual decrease of 5%	No change
	Change in costs for solar thermal and heat pumps	Annual decrease of 1%	Annual decrease of 2%	No change
No. estates in low carbon zones	Percentage of estates in low carbon zones	0%	0%	10%

BD scenario: sensitivity analysis assumptions

Factor	Variable(s)	Original Value	Low Value	High Value
Assumed Shadow Price of Carbon	Assumed Shadow Price of Carbon	£27.06 per tonne of CO_2 in 2011	£22.55 per tonne of CO_2 in 2011	£76.67 per tonne of CO_2 in 2011
Cost of biomass boilers	Installation and maintenance costs for biomass boilers, and fuel costs	Fixed installation costs: £4459 per dwelling; Variable installation costs: £731 per kWth; annual maintenance costs: £114 per dwelling; fuel costs: 2.5p per kWh in 2006	Fixed installation costs: £3567 per dwelling; Variable installation costs: £366 per kWth; annual maintenance costs: £57 per dwelling; fuel costs: 2p per kWh in 2006	Fixed installation costs: £5351 per dwelling; Variable installation costs: £1096 per kWth; annual maintenance costs: £171 per dwelling; fuel costs: 3p per kWh in 2006
Cost of heat pumps	Installation and maintenance costs for GSHPs and ASHPs	GSHP installation cost: £13548 per dwelling; ASHP fixed installation cost: £8378 per dwelling; variable installation cost: £279 per kWth; Annual maintenance costs for both £57 per dwelling	GSHP installation cost: £9484 per dwelling; ASHP fixed installation cost: £5864 per dwelling; variable installation cost: £195 per kWth; Annual maintenance costs for both £40 per dwelling	GSHP installation cost: £17613 per dwelling; ASHP fixed installation cost: £10891 per dwelling; variable installation cost: £363 per kWth; Annual maintenance costs for both £74 per dwelling
Efficiency of biomass boilers	Efficiency of biomass boilers	85%	80%	90%
Efficiency of heat pumps	Coefficient of performance for producing heat and hot water using GSHPs and ASHPs	GSHPs: 2.4 for heat, 1.68 for hot water; ASHPs: 1.88 for heat, 1.31 for hot water	All values decreased by 10%	All values increased by 10%

Sensitivity analysis assumptions for variables that do not affect original results